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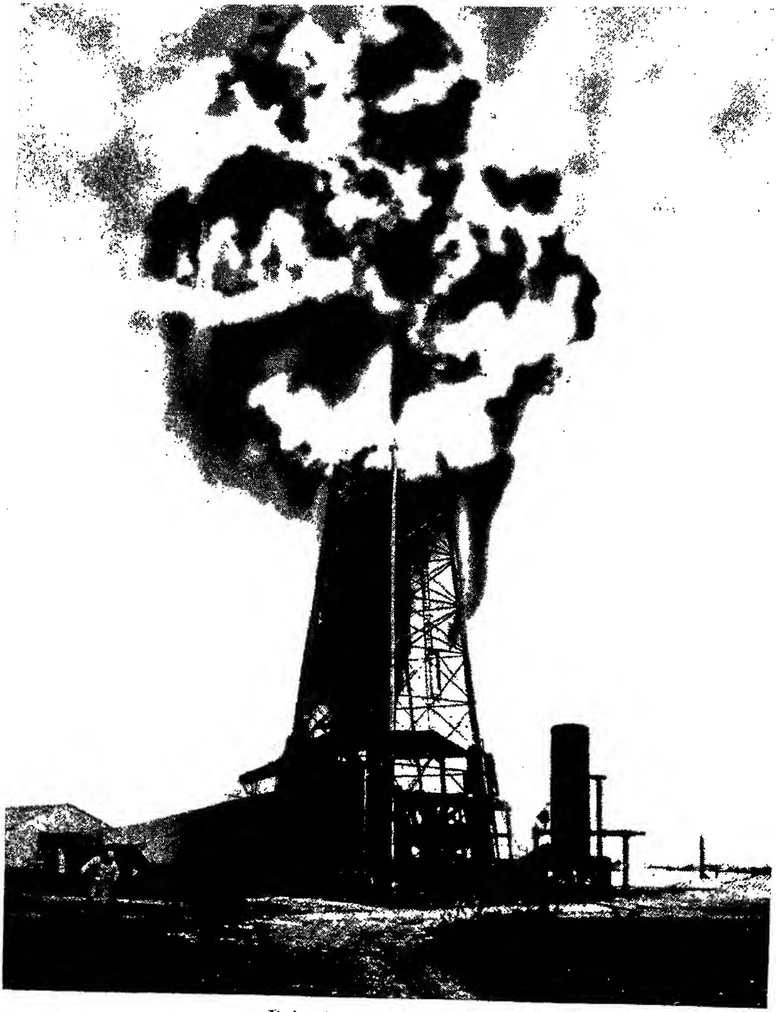

Bringing in an oil well.

OIL FUELS AND BURNERS

With Special Reference to Automatic Domestic Types

BY

JAMES A. MOYER

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PREFACE

Oil fuels have been in increasing demand during the last two generations and especially since the Columbian Exposition in Chicago in 1893 when the first large heating plant operated by oil burners was installed. Doubtless the publicity that was given oil fuels by the nationwide descriptions of this heating plant had much to do with the later rapid growth of the petroleum oil industry, especially for heating and power purposes. Some idea of the remarkable developments in this industry may be obtained from the fact that during each decade since about 1870 the production of oil fuels intended for heating and power had exceeded all the previous production up to the beginning of that decade. From time to time, experts in crude-oil production have predicted an early exhaustion of the reserve pools in this country, but as the demand for petroleum products has increased, there has also been a corresponding increase in the reserves.

This book is an extension of a course on oil burners that was prepared recently by the author for the Education Bureau of the United States Navy. This course as originally prepared was intended to cover especially the marine service in which oil-burning equipment was being used.

The recent large development in oil burners, however, has been of the automatic type intended especially for the heating of residences and apartment houses. The descriptive matter that goes with the applications of oil-burning apparatus for industrial and marine purposes is simple in comparison with the extra equipment that is necessary for the successful operation of automatically operated oil burners.

On account of such new applications and developments, there has appeared a demand for an informational manual intended especially for the needs of service men, salesmen, mechanics, electricians, and engineers who are engaged in servicing, planning, and designing in this field.

A new, related line of work immediately associated with oil burners is the heat insulation of walls, roofs, and floors in old

as well as newly constructed buildings. A chapter on Heat Insulation has therefore been included.

Because many up-to-date oil-burner manufacturers and distributors now furnish combined oil-burner and air-conditioning equipment, a chapter on Air Conditioning is included. It is hoped that those who study this chapter will be among the first in this field to discourage the installation of such equipment when it is entirely inadequate and unsatisfactory for the intended service. Much of the cheap equipment now offered for such service works out to no permanent advantage for the manufacturer or the person responsible for the installation.

In the preparation of the manuscript of this book, the author is especially indebted to Professor DeWitt M. Taylor, University of British Columbia, Vancouver; Mr. W. Albin Johnson, Instructor in Oil Burners, Massachusetts Division of University Extension; Mr. Harry F. Tapp, American Oil Burner Association, New York, N. Y.; Mr. A. V. Hutchinson, Secretary, American Society of Heating and Ventilating Engineers, New York; and James H. Walker, Detroit Edison Company, Detroit, Mich.

Representatives of the following oil-burner manufacturers have cooperated by furnishing descriptive information: Automatic Burner Corporation, Chicago; Borg-Warner Corporation (Norge Heating Division), Detroit, Mich.; Delco Appliance Corporation, Rochester, N. Y.; General Electric Company, Schenectady, N. Y.; George R. Bascom Company (Zenith Automatic Oil Burner Division), Boston; Julien P. Friez and Sons, Inc., Baltimore, Md.; Gould Oil Burner Corporation, Cambridge, Mass.; Johns-Manville, New York; Minneapolis-Honeywell Regulator Company, Minneapolis, Minn.; Petroleum Heat and Power Company (Petro-Nokol Division), Stamford, Conn.; Sears, Roebuck and Co., Chicago; Timken-Detroit Company (Silent Automatic Division), Detroit, Mich.

THE AUTHOR.

STATE HOUSE,
BOSTON, MASS.,
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OIL FUELS AND BURNERS

CHAPTER I

OIL FUELS

Crude Oil.—Almost without exception, the fuels now used for heating with oil burners are petroleum products, all of which for safety reasons are heavier than the gasolines and naphthas.* The basic petroleum oil is a greenish-black liquid which is called "crude oil." Although a little lighter than water, it has a "heavy" consistency much like molasses.

History of Petroleum.—Petroleum oil or rock oil has a very ancient history. In the book of Job in the Bible there is a mention of "rock that poured . . . out rivers of oil." Marco Polo, writing in the thirteenth century about his Far Eastern travels, states that in the Baku district in Siberia "there is a fountain from which oil springs in great abundance. It is not good to use with food," he says, "but is good to burn." We know also that the prehistoric American Indians burned crude petroleum oil and their "medicine men" used such oil for healing. The Vestal Virgins probably used petroleum oil in lamps which were provided with wicks made of a mineral substance, probably asbestos, which had the property of "licking up" oil in the same way as any other wick.

Occurrence of Crude Oil.—This petroleum oil is found in its natural state below the surface of the earth in pools under rock formations. These pools do not usually contain exclusively crude oil, as there is generally in the same chamber at a lower level some salt water, and above the pool there is quite generally a supply of *natural gas* which has a petroleum origin. The practical method of obtaining crude oil from the rock-bound pools is to drill a well in very much the same way that artesian wells are made. They are drilled to such a depth through the ground and rock that an oil pool may be tapped. When an oil pool is

* There is a large fire hazard when the easily ignited light petroleum products like gasoline and naphtha are used.

tapped by one of these wells, the pressure of the natural gas is usually great enough to force the crude oil up through the tubing that has been used for making the wall of the well. In a new well there is usually produced by the gas pressure sufficient force to discharge the oil with high velocity above the mouth of the well. During the time that the natural-gas pressure is effective for the discharge of the oil, the only discharge equipment needed at the surface of the ground is a suitably designed cap to put over the steel lining of the well, and pipes which can be attached to this cap for carrying the oil first to central reservoirs, usually enormous tanks, and finally to the oil refineries, where the different grades of oil are made from the crude oil. When, however, the gas pressure becomes depleted, so that the oil is no longer forced by gas pressure up to the surface of the ground, the production of the well can usually be continued for a long time by pumping the oil from the subterranean pools.

Elements Found in Crude Oil.—Carbon and hydrogen are the principal elements in all of the oil fuels. Over 90 per cent by weight of all the kinds of crude oil that have commercial value consist of these two elements; in fact, in some very high grades of crude oil between 98 and 99 per cent of the weight is carbon and hydrogen. Some kinds of crude oil, especially those from the south-western part of the United States, contain a considerable amount of sulphur. The sulphur content is combustible, so that in regard to heating alone there is not much disadvantage in using oil that contains some sulphur. On the other hand, the combustion of sulphur in the presence of water has a very strong tendency to produce corrosion of iron and steel. For this reason, manufacturers of refined petroleum oils are careful to have the sulphur content relatively low* because the combustion of the fuel produces some water vapor (see page 25).

* The chemical symbol for carbon is C, for hydrogen is H, and for oxygen O. It is interesting to remember these symbols, because later there will be references to the gases of combustion, particularly to CO, which is *carbon monoxide* (containing one atom of carbon and one atom of oxygen), and CO_2, which is carbon dioxide (containing one atom of carbon and two atoms of oxygen). Water has the chemical formula H_2O, meaning that there are in each molecule of water two atoms of hydrogen and one atom of oxygen. Carbon and hydrogen are combined in a variety of ways in gas and liquid fuels, such as methane (CH_4), ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), and decane ($C_{10}H_{22}$).

Petroleum Refining.—The various petroleum products obtainable commercially for heating (or for engine power) are produced in factories called "refineries" in which, by the application of heat to the crude oil, various distillates are obtained. When crude petroleum oil is heated in large, closed retorts or stills, vapors of varying density are given off, the lighter vapors, of course, coming off first. These light vapors when condensed are petroleum fuels like gasoline, naphtha, and benzene. When there is ordinary atmospheric pressure in such retorts or stills, these lighter vapors begin to rise from the surface of the crude oil when the applied heat has raised the temperature of the crude oil to about 100°F. and, as a rule, these light vapors are collected from the retorts or stills until the temperature has risen to about 125°F. If heating is continued after these lighter vapors have been removed, heavier vapors may be collected, and these, when condensed, give in succession (according to the vaporizing temperature) kerosene, fuel oils for household use, light lubricating (engine) oil, fuel oil of the residue type, and paraffin. No definite percentages can be stated as to the relative amounts obtainable from crude oil, of the light oils of the gasoline variety, kerosene and the light fuel oils, for much depends on the kind (especially the source) of the crude oil that is used. When the temperature of the crude oil has been raised to about 350°F., further distillation will permit the collection first of light and then of the heavy lubricating oils, and finally of the fuel oils.

Cracking Process of Petroleum Distillation.—If considerable pressure above atmospheric is maintained by an air compressor or by other means, the distillation of the light vapors can be continued even when the temperature is very much above the limits prescribed for the distillation at atmospheric pressure of the light oils of the gasoline variety. Some kinds of heavy crude oil from middle-western and western states give relatively little light oils of the gasoline variety when heated at atmospheric pressure, but large amounts of the light oils may be obtained when the crude oil is under pressure when heated. Briefly, the so-called *cracked* gasoline is obtained by breaking up or "cracking" the molecules of the crude oil by the application of both *heat and pressure* to the residue left after taking off the light "gasoline-type" oils that are vaporized in the ordinary refining process up to a temperature of 125°F. at atmospheric pressure.

Rate of Petroleum-oil Production.—During each succeeding ten years since the drilling of the first oil well in Pennsylvania, there has been a production of oil equal to, or greater than, the total production everywhere in this country throughout all the previous years of oil production. Thus, from 1920 to 1930 more oil was taken from the ground through wells than was produced in this country during the whole period from 1860 to 1920. This production has gone on in spite of the fact that estimates made by experts in the industry have from time to time predicted that

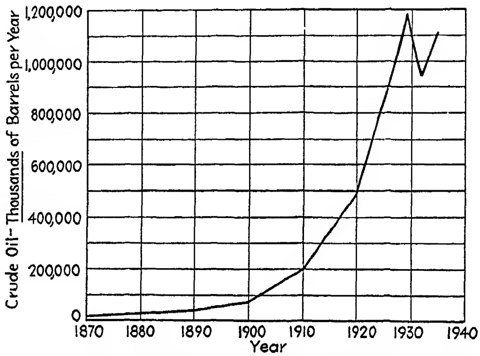


FIG. 1.—Oil production in United States since 1870.

previous rates of production could not be maintained for many years without serious depletion of the available underground supplies. A survey of the total untapped oil reserves in this country was made by the U. S. Geological Survey in 1908 with nearly 300 per cent added for "probable error," and before 1925 the total production of the intervening years had exceeded by a large amount the maximum estimates of the Geological Survey. Oil production in the United States since 1870 is shown in Fig. 1.

Since the early days of the oil industry, there have been periodic predictions of an oil shortage within a relatively short time, but as the industry has grown, the available supplies have also increased in a much larger proportion, so that in recent years there has been a large overproduction of oil from producing wells.

In this connection, the following statement by W. C. Teagle, president of the Standard Oil Company of New Jersey, is interesting:

"I have full faith in the ability of the oil industry to meet the growing demand for oil for domestic heating purposes. The experience of

the last generation plus the best forecast which science can make for the coming generation justifies such faith.

"The modern domestic oil burner gives a kind of household heating service which gas alone has supplied in the past, and in the country as a whole it gives that service cheaper. In my opinion, oil heating will not only supplant gas, which is its present sole competitor, but, like the gasoline automobile, will establish a new standard of American home life and fix a level of comfort and convenience never before attained by any civilization, and at a price well below the limit of its economic value for that use."

From 1860, when Colonel Drake "struck oil" in western Pennsylvania, to 1893,* crude petroleum oil was used mainly for the manufacture of lubricants, kerosene, paraffin, and naphtha.

At the same time that the industrial applications of petroleum oil were going forward, there was experimentation that had as its object the use of such oil for domestic heating. All the devices used in this early stage of development were quite crude in design and consisted in most cases of merely a tank filled with the oil fuel and fitted with a pipe so located that the oil could discharge from it in drops upon a hot refractory material, which was used as the lining of a pan-shaped container.

It was only a short step from this design to that of the natural-draft vaporizing burner (page 43). However, even the latter burner was difficult to manipulate, and initial heating of the refractory material in the firepot of the burner by some means other than fuel oil was necessary. Besides operation was unreliable. As a further improvement, oil burners were developed with an attached ventilating fan or blower which forced air for combustion into the firepot of the burner. The fan-equipped oil burner embodied the fundamental idea in the later designs of mechanical-draft, automatic types, which came into use to a very limited extent about 1920. Automatically controlled oil burners supply nearly uniform heat at all seasons by the operation of a suitable temperature-control device called a *thermostat*. The good fuel economy that is obtainable throughout all of the months of the year, whether a large or a small heat supply is needed, has impor-

* The buildings of the World's Fair at Chicago in 1893 were heated by oil fuel. This use of oil for heating attracted a great deal of attention at the time.

tant significance in respect to fuel costs; but the really important advantages of oil fuel are comfort, convenience, and cleanliness. The storage of the oil fuel may be in an out-of-door tank or in a compact indoor tank that can be put in a more or less inaccessible place in a basement or cellar.

The Lucigen air-blast burner, patented in 1885 and intended for *lighting* large areas, was the first large-size oil burner. It produced a flame 30 inches long and 10 inches in diameter.

Oil Fuel from Shale.—The question of the future production of petroleum in this country is a disputed one, as one group of

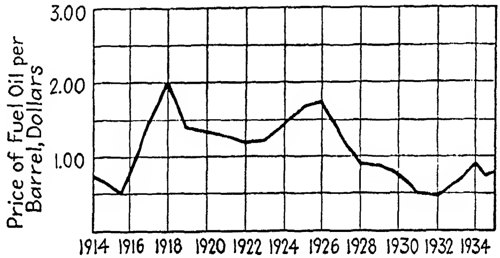


FIG. 2.—Price changes of fuel oil.

people believe that there is danger of a shortage within the next few years while another is confident that the petroleum supplies of the country will be adequate to meet the demand for a long period of time, especially when taking into account the very large deposits of oil shale which are adequate for the production of many billions of barrels of fuel oil, gasoline, and similar petroleum products.

It is difficult to furnish adequate information as to the price at which petroleum can be produced from oil shale. A number of oil-shale plants were operated on a semicommercial scale a few years ago by the method of recovering a heavy grade of oil from the shale and not refining it but marketing it at fuel-oil prices. Shale oil cannot compete with crude oil from the wells until Midcontinent crude oil reaches a price of $4 to $5 per barrel.

The available deposits of oil shale are almost unlimited, so that with the further development of the coal-distillation process, it will be possible when necessary to produce large quantities of petroleum oils suitable for fuel from present undeveloped sources. The history of the oil industry shows that production as well as

price goes in unequal cycles. The price changes of fuel oil are shown in Fig. 2. Adherence to the economic law of supply and demand is, of course, fundamental. When there are price increases, production also, as a rule, increases, with the result that new sources of supply are opened up. Soon, because of this increased production, prices will be lowered and consumption will be increased until the amount of oil in storage is being reduced. When it becomes apparent that storage supplies are being drawn on, prices will again rise, and the cycle of price and production will be repeated. In this connection, it is significant that the reserve supplies have always been sufficient to keep the price of fuel oil within a comparatively narrow range.

Drilling operations for the bringing in of new oil wells, as they are now conducted for deep drilling in most of the new oil fields, are necessarily very expensive, and involve the outlay of large sums of money on a speculation, as there can be no certainty that a new oil well is going to be productive. The large cost of well drilling and the uncertainty of results have served as a brake to retard exploration and "wild-cat" drilling until the price of oil is high enough again to warrant attempts to secure new production. During a period of increasing production, there is always a reluctance on the part of producers to stop their drilling operations for new oil wells, so that the bringing in of new wells is likely to continue during an increasing production cycle, until such operations actually become unprofitable.

The discovery of new oil fields brings in such large quantities of cheap oil that it becomes unprofitable to operate the oil wells that have receded from a "flush" production to a "settled" production. In this sense, a "settled" production from an oil well means that it has passed the stage of maximum yield and has settled into a production of a small but fairly constant amount. When the "settled" oil wells are shut down because of overproduction in the same field or other fields, the amount of oil that goes into storage becomes less and less, and if the reductions due to shutting down are not equal to the increasing production, the price structure becomes unstable, and eventually the refinery storage capacity will be taxed to the limit and a great deal of oil from new wells is likely to be wasted.

New Industries Fostered by the Availability of Large Oil Supplies.—Three decades ago, the rapid development of the

automobile was a significant factor in the growth of the oil industry; and during the last generation, the introduction of domestic oil burners opened a field for the use of large quantities of oil fuels. Fortunately, the automobile uses a relatively light type of the petroleum products and the oil burner is usually intended to use a much heavier grade. For this reason, each of these two uses of petroleum products tends to supplement the other in such a way as to lead to an almost ideal utilization of the petroleum resources of the country.

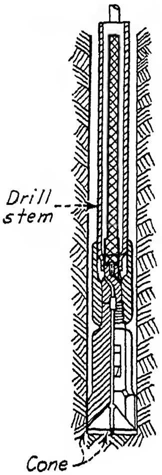


FIG. 3.—Rotary bit for oil-well drilling.

Equipment for Drilling an Oil Well.—The superstructure of an oil-producing unit is the well-known high tapering *derrick* which is the supporting means for the so-called "drilling rigs." In the rotary system of drilling, which is the modern method, the "rig" consists of a rigid stem of iron piping which rotates a drilling bit used to force its way through rock and sand. A sectional view of such a rotary bit is shown in Fig. 3.

An older method of drilling oil wells was with the use of a drilling tool which was suspended on a cable and connected to the walking beam of an engine. The up-and-down movement of the walking beam of the engine made the tool move up and down with

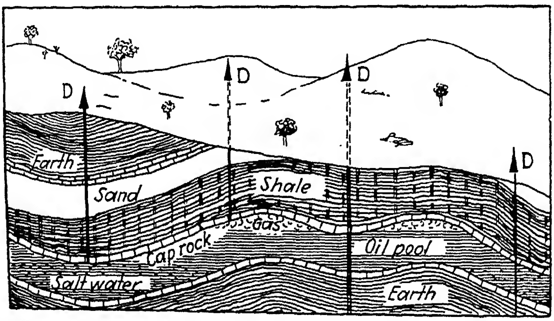


FIG. 4.—Cross section of earth in oil field.

regularity, so that by its weight it would work its way through earth or rock formations.

A typical cross section of the earth in an oil-producing field is shown in Fig. 4. Until quite recent years, very few oil wells were drilled to a greater depth than a few hundred feet. With modern methods of drilling, oil wells can be made much deeper than was possible formerly, and it is not unusual now to drill oil wells that are several thousand feet deep. As shown in the last figure, there is usually a large volume of gas imprisoned in the earth on the surface of an oil pool. This gas, called "natural gas," is usually present under these conditions at a pressure which is high enough to force the oil from the oil pool up through the drilled well, so that it spurts with high velocity from the ground surface. A spurting oil well of this kind is called a "gusher." On the other hand, when oil wells are drilled, it happens frequently that the driller does not enter an oil pool, but does penetrate a cavity that is filled with high-pressure gas. In that case, the discharge from the well is only a gas of petroleum origin. Natural gases from this source are sometimes carried in pipe lines to very great distances, as, for example, from Oklahoma to cities in northern Illinois. Still other drilled wells—and there is a considerable number of them in every oil field—will never discharge either oil or gas; these are called "dry holes."

New oil fields are constantly being redeveloped by the method of deeper drilling, so that old oil wells that have been nearly exhausted will be brought in again for large production, sometimes with "gusher" discharge.

Constituents of Petroleum Oil from Wells.—The petroleum oil discharged from wells is called "crude oil." This is a compound of a number of oil constituents which may be separated by *distillation*. Each of the constituents has a different boiling point, ranging from the low boiling points of naphtha or gasoline to the high boiling points of fuel oil and paraffin. *Crude oil* may be classified in general according to chemical composition into three classes as follows: (1) Paraffinic base oil; (2) asphaltic base oil; (3) naphthenic base oil. In connection with this classification, it must be kept in mind, however, that the crude oils from some districts are a combination of all three classifications. Thus, a Pennsylvania crude oil may have constituents which are related mostly to a paraffinic base oil with a small percentage of asphaltic base oil. On the other hand, some kinds of crude oil from Mexico are mostly asphaltic and Russian crude oils are naphthenic, with,

however, constituents in small amounts that have both a paraffinic and an asphaltic base.

Chemical Composition of Crude Oils.—In their chemical composition, all grades of crude oil are composed *by weight* of from 80 to 87 per cent of carbon (C) with from 10 to 15 per cent of hydrogen (H). In addition to these elements, there are small percentages of oxygen (O), nitrogen (N), and sulphur (S). Typical ultimate analyses of various types of crude oil are given in Table I.

TABLE I.—CHEMICAL COMPOSITION OF VARIOUS OILS

Type of oil	Specific gravity, Bé deg. (page 197)	Ultimate analyses			
		Carbon, per cent	Hydrogen, per cent	Sulphur, per cent	Oxygen and nitrogen, per cent
Kerosene	40	84.7	15.3	trace	
California crude	16	81.0	11.6	0.5	6.9
Pennsylvania or Ohio crude	28	86.0	12.3	trace	1.6
Oklahoma crude	31	84.7	11.3	4.0	
Kansas crude	31	85.4	14.6	trace	
Texas crude	20	85.3	12.3	1.7	0.7
Mexican crude	14	84.7	10.2	4.1	1.0
Russian crude	17	86.6	12.3		1.1

The Pennsylvania type of crude oil, of which the base is largely paraffinic, is the most valuable, since it contains many grades ranging from gasoline in large amount to high-grade lubricating oils. The crude oils that have an asphaltic base contain a grade of gasoline that is different from that in a paraffinic-base crude oil, and furthermore, gasoline is present in much smaller quantities. Asphaltic-base crude oils are generally refined in "skimming" stills where only the lighter products like gasoline and kerosene are removed by distillation and the residue which contains large quantities of wax and asphalt may be sold as fuel oil, but much of it is used also as asphalt for making street pavements.

Petroleum-distillation Methods.—As already stated in the preceding paragraph, distillation methods will vary with the type of crude oil that is to be refined or distilled. The general practice in refining crude oil consists in the first place of separating

the constituent oils by the application of heat. In this process of separation, the various constituents are drawn off in the following order: (1) naphtha; (2) gasoline; (3) kerosene; (4) lubricating oil; (5) fuel oil; (6) asphalt (from grades of crude oil from which it is obtainable).

The separation by distillation is possible for the reason that the various hydrocarbon groups have different boiling points (page 20). For this separation by ordinary heat distillation, the equipment used is called a "crude still." There are three somewhat standard methods of operating these stills for refining crude petroleum which may be explained as follows:

1. *"Batch" or Single-unit Operation.*—By this method a charge of crude oil is boiled down in a single still until only coke remains.

2. *Series Operation of Stills.*—By this method, crude oil is gradually reduced in gravity in a succession or series of two or more stills constituting what is called a "battery." As the residue of the crude oil is pumped from one still to the next, the lighter constituent oils are given off until in the last stages of the process of distillation the tar is removed and only coke remains in the last still of the battery.

3. *Pipe or blast stills* are used for the distillation of Mexican or similarly constituted crude oils, so that the lighter constituent oils may be skimmed off (page 10) the surface of the still, leaving in the stills at the end of the process heavy fuel oils and tar.

In the process of distillation by any of the three methods, each of the lighter liquid constituents in the crude oil is removed in the process in the form of vapor. The vapor of each grade of petroleum oil is condensed in water-cooled coils, as it comes from the still.

In the refining process, as described, each of the constituents separated from the crude oil is collected in a separate tank. A typical refinery flow chart is shown in Fig. 5. Neither the light nor the heavy oils are finished products as collected in the tanks at this point in the distillation process, but they require further treatment in the so-called "re-run stills," steam stills, and cracking stills. In these other stills, there occurs subdivision of the various grades with more clearly defined limits. In this further treatment in the stills, chemical treatment is also required before the lighter refined products such as naphtha, gasoline, and kerosene are suitable for commercial use. Sulphur and other impuri-

ties must be removed, mostly by chemical means. Sulphur when present in oil together with water has a deleterious effect on parts made of iron or steel; and impurities must be removed in order to eliminate odor and unsatisfactory color. The impurities, unless removed, are likely to cause deterioration of the light-oil constituents during storage. In the first part of the chemical treatment, the oil is subjected to vigorous agitation with sulphuric acid. As the result of this agitation, the acid and sludge settle

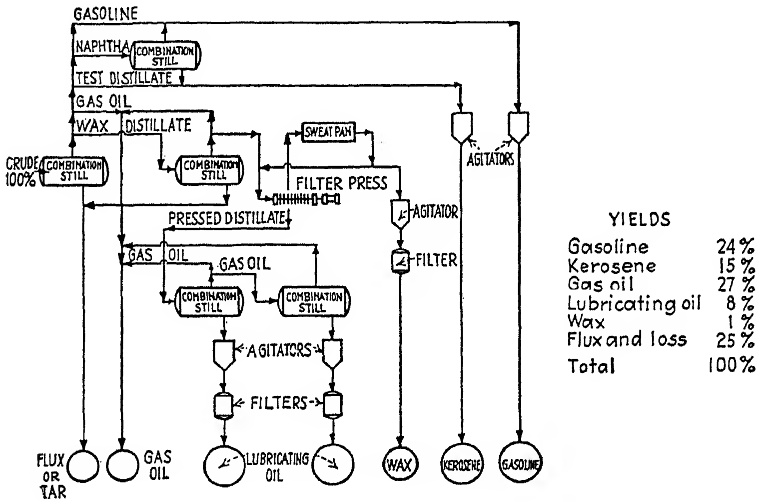


Fig. 5.—Typical refinery flow chart.

to the bottom of the tank in which the agitation takes place and can then be conveniently removed. After this acid treatment, the refined oil is washed with water and agitated again with a caustic-soda solution to remove any traces of acid that might remain in the treated oil.

Cracking Process.—The amount of gasoline that can be produced by the ordinary methods of refining, as explained, is not nearly sufficient for the present large demand, and consequently some refineries use the *cracking process* in order to increase the yield of light oils from crude oil. When crude oil is treated in a still, the lighter oils are removed from the crude oil without any change in their chemical composition, provided the distillation temperature does not exceed 580°F. After this temperature

is reached, any increase is likely to cause decomposition, which occurs slowly at first but more rapidly as the temperature is increased; and at a temperature of 700°F. a really appreciable decomposition has taken place. By increasing the temperature of the crude oil from 750° to 900°F., the heavy hydrocarbons are largely decomposed into lighter hydrocarbons. These high temperatures are, of course, above the boiling points of the light oil, so that in the cracking* process as thus applied it is necessary to heat the residue oil in a tightly closed tank, in which the pressure can be increased sufficiently to prevent boiling at relatively low temperatures.

To some extent, the quality and quantity of the refined oil products from the cracking system can be controlled, although the control is not so accurate as by the hydrogenation method (page 14) which will be explained later. The control that is possible in the cracking process is obtained by varying the conditions of temperature, pressure, and duration of heating; that is, whether the heating takes place only while the charging stock is in the liquid state or whether the heating occurs not only during the time the charging stock is liquid but also when some or all of it has become a vapor.

The duration of the time of heating in the application of the cracking process has led to the development of various cracking systems, all of which, however, can be divided into the following two classes:

1. The *liquid-phase system,* in which the heat is applied to the charging stock, with the desired pressure in such amount as to maintain continuously throughout the process the liquid condition.

* A cracking sound is produced in the tank when this decomposition of heavy hydrocarbons is going on, and this fact has given the name to the operation. There is no general agreement among chemists as to just what is the chemical reaction that occurs during the process. It is known, however, that in the first place the reaction is accompanied by the formation of methane gas (CH_4), but in the second part of the reaction practically no gas is formed, which seems to indicate that the decomposition is accompanied by the reaction known as polymerization which means the formation of hydrocarbons of greater molecular weight than that of the heaviest hydrocarbons that existed in the crude oil that is being used.

A more complete statement of the probable chemical reactions that occur during the cracking process is given in the "Handbook of Oil Burning" by H. F. Tapp, p. 30, 1931.

2. The *vapor-phase system* in which the charging stock is heated not only while it is in the liquid condition, but also when some or all of it has been vaporized. Both the liquid-phase system and the vapor-phase system are controlled by fundamental patents. The final petroleum products from the two methods are about the same.

Hydrogenation.—Another process for decomposing hydrocarbons is known as hydrogenation. In this process the light hydrocarbons obtainable from crude oil, especially gasoline, kerosene, and light furnace oils, are very much increased in amount by adding hydrogen (H) to the heavier hydrocarbons with the application of heat and very high pressure in the presence of a *catalyst*. The chemical reaction that takes place in this process is about as follows:

$$C_nH_{2n} + H_2 + \text{(heat and high pressure)} = C_nH_{2n+2} \quad (1)$$

The essential difference between the hydrogenation process and the cracking process is that in the *cracking process* the heavy hydrocarbons are reduced by the extraction of carbon and as a result the total quantity of liquid oils at the end of the process is less than the quantity in the original charge of crude oil. In the hydrogenation process the total quantity of liquid at the end of the process may be equal to, or greater than, the original volume of the crude oil used as charging stock.

The hydrogenation process of oil refining was developed originally by the I. G. Farbenindustrie in Germany; and the Standard Oil Company of New Jersey assisted in the commercial development of the process for commercial application. The American company put into operation a refining plant using the hydrogenation process at Bayway, N. J., in 1930, and this plant has been operated since that time mostly for the production of high-grade lubricating oils. The advantages of the hydrogenation process are mainly that (1) there is better operating control and therefore greater uniformity in results than by other methods, and (2) it serves as a means for balancing production against demand with respect to the production of light products, especially gasoline, as well as also the much heavier *Diesel-engine fuels* that are coming into constantly greater demand. In other words, hydrogenation serves as a means for regulating at will the percentages of light, medium, or heavy distillates that are desired.

Experience in actual operation of the hydrogenation process shows that the cost of distillates by this method is prohibitive for the production of gasoline at present prices but can be used commercially for making lubricating oils to meet difficult specifications.

Specifications for Furnace and Fuel Oils.—Not many years ago, furnace and fuel oils were specified as to quality by the specific gravity (page 197). It has been known, however, for a long time that gravity tests alone do not give sufficient information in regard to the burning qualities of any of these oils. Of two grades of fuel oils, for example, having the same gravity test, one may have a much higher or a much lower flash point than the other, and the two oils may also be quite different in regard to properties of flow (viscosity).

It is not an unusual occurrence to find in different parts of the country two kinds of oil that have exactly the same *specific gravity* test that may or may not operate satisfactorily in an oil burner of a given make. Frequently manufacturers and selling agents of oil burners have had to face such difficulty, and consequently an entirely different method of specifying the properties of furnace and fuel oils has been adopted. In cases, therefore, where specific gravity is the only specification required in the purchase of furnace and fuel oils, it is practically impossible to expect even a reasonable amount of uniformity in the characteristics of the oil that make it suitable or profitable for the type of burner in which it is to be used. In this connection, it may not be out of place to explain that the term "fuel oil," as ordinarily used by the manufacturers and sellers of oil burners, is the residual product of the crude oil remaining after the naphtha, gasoline, kerosene, and other more valuable oils have been removed by distillation. The modern method of specifying for the desired properties of fuel oil is to use the Commercial Standard Grade Numbers. This number classification has been adopted by the American Oil Burner Association, the American Society for Testing Materials, the American Petroleum Institute, and the U. S. Bureau of Standards. According to this grading, there are six classifications, all designated now as fuel oil, but including in this terminology the so-called light furnace oils. The standard specifications, according to number, as adopted by these associations and institutions, are given in Tables II and III.

TABLE II.—DOMESTIC DETAILED REQUIREMENTS FOR FUEL OILS

Grade of oil	Flash point, °F. (page 38)		Water and sediment, maximum, per cent (page 223)	Pour* point, maximum, °F. (page 218)	Distillation test °F.			Viscosity, maximum at 100°F.
	Minimum	Maximum			10 per cent point maximum (page 207)	End point (page 207)	90 per cent point, maximum and minimum (page 207)	
No. 1, light domestic fuel oil (a light distillate oil for use in burners requiring a volatile fuel)	100 or legal requirement	150	0.05	15	420	600 (max.)		
No. 2, medium domestic fuel oil (a medium distillate oil for use in burners requiring a volatile fuel)	110 or legal requirement	190	0.05	15	440	600 (min.)	620	
No. 3, heavy domestic fuel oil (a distillate fuel oil for use in burners where a low viscosity oil is required)	110 or legal requirement	200	0.1	15	460	.....	675	Saybolt universal tester, 55 seconds (page 213)

* Lower or higher pour points may be specified whenever required by conditions of storage and use. However, these specifications shall not require a pour point less than 0°F. under any conditions.

Sulphur in Fuel Oil for Special Uses.—Recognizing the necessity for low-sulphur fuel oils used in connection with heat-treatment, furnaces and other special uses, a sulphur requirement may be specified in accordance with the following table:

Grade of Oil	Maximum Per Cent of Sulphur
No. 1	0.5
No. 2	0.5
No. 3	0.75
No. 4	1.25
No. 5	no limit
No. 6	no limit

Carbon Residue.—The maximum percentage of carbon residue according to the latest standard government requirements is

TABLE III.—INDUSTRIAL DETAILED REQUIREMENTS FOR FUEL OILS

Grade of oil	Flash point, °F. (page 38)		Water and sediment, maximum per cent	Pour point, maximum °F. (page 218)	Viscosity,
	Minimum	Maximum			
No. 4, light industrial fuel oil (an oil known to the trade as a light fuel oil for use in burners where a low-viscosity industrial fuel oil is required)	150	*	1.0	†	Saybolt universal tester (page 213) at 100°F. 500 seconds max.; 70 min.§
No. 5, medium industrial fuel oil (same as Federal Specifications Board specification for *bunker oil* "B") for burners adapted to the use of industrial fuel oil of medium viscosity	150	....	1.0	....	Saybolt Furol tester (page 215) at 122°F. 100 seconds max; 25 seconds min.
No. 6, heavy industrial fuel oil (same as Federal Specifications Board specification for *bunker oil* "C") for burners adapted to oil of high viscosity	150	....	0.2‡	....	Saybolt Furol tester at 122°F. 300 seconds max.; 100 seconds min.‖

* Whenever required, as, for example, in burners with automatic ignition, a maximum flash point may be specified. However, these specifications shall not require a flash point less than 250°F. under any conditions.

† Pour point may be specified whenever required by conditions of storage and use. However, these specifications shall not require a pour point less than 15°F. under any conditions.

‡ The total water plus sediment shall not exceed 2.0 per cent.

§ This requirement shall be waived when the carbon residue is more than 1 per cent.

‖ This requirement shall be waived when the carbon residue is more than 4 per cent.

0.02 for No. 1 oil, 0.05 for No. 2 oil, and 0.15 for No. 3 oil. No standard carbon residue requirement is given for heavier oils;

but instead, there is a maximum permissible ash requirement of 0.1 per cent for No. 4 oil and 0.15 per cent for No. 5 oil.

The specifications given in Table II are intended to cover light, medium, and heavy domestic fuel oils, and those given in Table III are for light, medium, and heavy industrial fuel oils which may be used for either domestic or industrial oil-burning equipment.

General Additional Specifications.—In drawing up formal specifications for the purchase of grades 1 to 4 of fuel oil, as classified in the preceding paragraph, it may be desirable to add that the specifications are for hydrocarbon oils free from water, acid, grit, and fibrous or other foreign matters likely to clog or injure the burner or valves; and also in the case of grades 5 and 6, the oil supplied shall be hydrocarbon oil free from grit, fiber, or other foreign matter likely to clog or injure the valves. Still another specification sometimes used is that the oil shall be strained by being drawn through filters or wire gauze having at least 16 meshes to the inch. "Clearance area" through the strainers shall be at least twice the area of the suction pipe and duplicate strainers shall be required.

TABLE IV.—SPECIFIC HEAT OF AMERICAN AND FOREIGN FUEL OILS

Locality of oil field	Specific gravity (g)	Specific heat (S)
California....	0.95	0.40
Pennsylvania	0.90	0.50
Japan.......	0.85	0.45
Russia.......	0.90	0.43

Specific Heat of Fuel Oil.—The ratio of the amount of heat required to raise 1 pound of a substance 1°F. to the amount of heat required to raise the temperature of 1 pound of water 1°F. is called the "specific heat of the substance." According to this definition, obviously, the specific heat of water is 1.0. In the same terms, the average specific heat of fuel oils is usually taken for approximate calculations as 0.5. Actually, there is some variation, depending on the field from which the fuel oil has been taken, as is shown by Table IV.

Heat Calculations.—Corresponding to the yardstick for length measurements, there is a unit for heat measurements that may be

conveniently used, and is called the *British thermal unit,* which, for short, is written B.t.u. It is the amount of heat required to raise the temperature of 1 pound of water 1°F.

By using the following equation, the amount of *heat necessary to raise the temperature of oil* may be conveniently calculated:

$$h = w \times S \times (t_2 - t_i) \qquad (2)$$

where h = total heat required, B.t.u.
w = weight of oil, pounds.
S = specific heat of oil (usually taken as 0.5, if exact data are not available).
t_2 = temperature to which oil is heated, degrees Fahrenheit.
t_i = initial temperature of oil, degrees Fahrenheit.

Coefficient of Expansion of Oil.—The rate at which the volume of oil expands per degree Fahrenheit as its temperature is raised, is called the coefficient of expansion. The following equation can be used to calculate the volume that will be occupied by a given volume of oil when heated:

$$v_2 = v_i \times [1 + c(t_2 - t_i)] \qquad (3)$$

where v_2 = volume of oil at final temperature.
v_i = volume of oil at initial temperature.
c = coefficient of expansion per degree Fahrenheit.
t_2 = final temperature, degrees Fahrenheit.
t_i = initial temperature, degrees Fahrenheit.

The values of the coefficient of expansion of oil vary with the specific gravity of the oil, as shown in Table V.

TABLE V.—COEFFICIENT OF EXPANSION OF PETROLEUM OIL

Specific Gravity °Bé. at 60°F.	Coefficient of Expansion per °F.
10	0.00352
15	0.00366
20	0.00381
25	0.00397
30	0.00415
35	0.00435
40	0.00457
45	0.00480

Latent Heat of Evaporation of Petroleum Oil.—The quantity of heat that must be added to oil at its boiling point to convert it

into a vapor is called the "latent heat of evaporation." This quantity is called "latent heat" for the reason that adding this amount of heat to any liquid at its boiling point does not increase its temperature. The latent heat of evaporation is given in British thermal units (B.t.u.) per pound (page 19) as in Table VI.

TABLE VI.—APPROXIMATE LATENT HEAT OF EVAPORATION OF PETROLEUM OIL

Boiling Point of Oil, °F.	Latent Heat of Evaporation, B.t.u. per Pound
100	153
200	138
300	125
400	114
500	104

The total amount of heat to vaporize a given weight of oil can be conveniently calculated with the help of the following equation:

$$h = w \times S \times (t_2 - t_i) + w \times e \qquad (4)$$

where h = total heat required to vaporize oil, B.t.u.
w = weight of oil, pounds.
S = specific heat of oil.
t_2 = boiling point of oil, degrees Fahrenheit.*
t_i = initial temperature of oil, degrees Fahrenheit.
e = latent heat of evaporation, B.t.u. per pound.

Measures of Volume—U. S. Gallon and Imperial Gallon.—The volume of a gallon as used in the United States is different from the Imperial gallon that is used in Canada and England. Frequently, it is necessary to make a conversion from one of these units of volume to the other. The following tabulation may, therefore, be useful in cases when such conversions are to be made. One U. S. gallon equals 231 cubic inches. One Imperial gallon equals 277 cubic inches. Six U. S. gallons equal five Imperial gallons. To convert U. S. gallons to Imperial gallons, *divide* by 1.2. To convert Imperial gallons to U. S. gallons, *multiply* by 1.2. One barrel of oil equals 42 gallons.

* This temperature is not always a definite value, because of the hydrocarbon variations in similar oils.

The weight of a U. S. gallon of oil, w_u, may be calculated by the following equation:

$$w_u = 8.33 \times \text{specific gravity of oil.}$$

Similarly, the weight of an Imperial gallon of oil w_i is

$$w_i = 10 \times \text{specific gravity of oil.}$$

Heat Value of Oil Fuels.—The heat value of a fuel is the amount of heat produced by burning a unit quantity of the fuel completely. It is usually expressed in British thermal units per pound of fuel. Since oil is sold by the gallon, values per gallon are also used.

For many calculations in connection with oil burning, it is useful to know the heating value of oil fuel per gallon. Approximate values of this heating value for the different commercial standard grades of fuel oils are given in Table VII.

Although the specific gravity of an oil is not a true index of its suitability as a fuel, experience has shown that it bears a very close relation to the heat value. From a study of the results of many laboratory heat-value tests, a formula has been developed which is said to be accurate to about 2 per cent. This formula is as follows:

$$\text{B.t.u. per } \textit{pound} = 18{,}440 + 40(\text{Bé.} - 10) \qquad (5)$$

where Bé. (page 197) is the specific gravity in degrees Baumé. This formula applies to the lighter oils. For the heavy oils the same formula is used, substituting 18,560 for the constant 18,440. If degrees A.P.I. (page 198) are used, the accuracy will still be satisfactory for field work.

It has also been noted that an oil which satisfies the specifications for one of the standard grades will *usually* fall into a fairly narrow specific-gravity range. For example, a No. 1 oil will *probably* have a gravity between 38° and 40°Bé. This does not mean that a gravity of 38° to 40° Bé. indicates a No. 1 oil.

Comparative Costs of Fuels.—The comparison must often be made of the cost of heating a building with oil fuel to some other fuel, especially gas or coal. Electricity must also be considered in cases where the cost of heating is not an important item, as, for example, the heating of toasters in a restaurant, of water in a

barber shop, of coffee in table urns, and so forth, where the electric heating has special conveniences.

Gas should really be considered as a suitable house-heating fuel only when burned in a boiler or warm-air furnace that has been specially designed for gas fuel. The principal reason for this

TABLE VII.—APPROXIMATE HEATING VALUES OF FUEL OILS OF STANDARD GRADES

Commercial standard grade, number	Approximate gravity range, °Bé.	Specific gravity	Heating value, B.t.u.	
			Per gallon	Per pound
1	38–40	0.83	135,000	19,600
2	34–36	0.85	138,000	19,400
3	28–32	0.88	141,500	19,200
3	Pacific Coast Diesel Oil, 24–26	0.90	145,000	19,000
4	24–26	0.90	145,000	19,000
5	18–22	0.93	148,000	18,800
6	14–16	0.95	151,000	18,600

statement is that the efficiency E_g of heating by gas in a boiler or furnace designed for a gas fuel is from 65 to 70 per cent, and when gas or oil fuel is used in a boiler or furnace designed for some other fuel, the efficiency E_o or E_g is not likely to be much higher than 60 per cent, even under favorable circumstances.* The average efficiency E_c of coal-fired boilers and furnaces is not usually more than 45 per cent. When the heating coils for electricity are directly applied to the medium being heated, the efficiency E_e is usually between 90 and 98 per cent.

The following notation may be used in the equations that follow to calculate the cost D *per day*, when each of the following heat sources is used: (1) fuel oil; (2) illuminating gas; (3) coal; and (4) electricity. In each case

H = total heating requirement of building per day, B.t.u.

E = efficiency of boiler, furnace, or other heating means, per cent.

* Most of the house heaters using oil burners at the present time were intended for burning coal. Adaptation is a common practice, and for this reason the general average boiler efficiency with gas is somewhat higher than with oil.

h_o = heating value of oil fuel per gallon (page 22), B.t.u.
h_g = heating value of gas per cubic foot, B.t.u.
h_c = heating value of coal per pound, B.t.u.
h_e = heating value of electricity per kilowatt-hour.
C_o = cost of oil fuel per gallon, cents.
C_g = cost of gas per cubic foot, cents = cost per 1,000 cu. ft. ÷ 1,000.
C_c = cost of coal per pound, B.t.u. = cost per ton ÷ 2,000.
C_e = cost of electricity per kilowatt-hour.

$$D_o \text{ (for oil)} = \frac{H \times C_o}{h_o \times \frac{E_o}{100}} \tag{6}$$

$$D_g \text{ (for gas)} = \frac{H \times C_g}{h_g \times \frac{E_g}{100}} \tag{7}$$

$$D_c \text{ (for coal)} = \frac{H \times C_c}{h_c \times \frac{E_c}{100}} \tag{8}$$

$$D_e \text{ (for electricity)} = \frac{H \times C_e}{h_e \times \frac{E_e}{100}} \tag{9}$$

Example.—A practical case in which the above equations are used will be interesting and useful for comparison in making other calculations. The cost D *per day* of heating a building at a season of the year when it requires 1,000,000 B.t.u. per 24 hours will be calculated when oil, gas, coal, and electricity, respectively, are used as heat sources.

For oil heating, assume H = 1,000,000 B.t.u., h_c = 140,000 B.t.u. per gallon, E_o = 60 per cent, and C_o = 7 cents per gallon.

$$D_o = \frac{H \times C_o}{h_o \times \frac{E_o}{100}} = \frac{1{,}000{,}000 \times 7}{140{,}000 \times {}^{60}\!/_{100}} = 83.3 \text{ cents per day.}$$

For gas heating, assume H = 1,000,000 B.t.u. (as before), h_g = 550 B.t.u. per cubic foot, E_g = 65 per cent, C_g = 0.065 cent (65 cents per 1,000 cubic feet).

$$D_g = \frac{1{,}000{,}000 \times 0.065}{550 \times {}^{65}\!/_{100}} = 181.8 \text{ cents or \$1.818 per day.}$$

For coal heating, assume H = 1,000,000 B.t.u. (as before), h_c = 12,000 B.t.u. per pound, E_c = 45 per cent, C_c = 0.60 cent per pound ($12 per 2,000 pounds).

$$D_c = \frac{1{,}000{,}000 \times 0.60}{12{,}000 \times {}^{45}\!/_{100}} = 111.1 \text{ cents or \$1.11 per day.}$$

For electric heating, assume H = 1,000,000 B.t.u. (as before), h_e = 3,413 B.t.u.* per kilowatt-hour, E_e = 96 per cent, C_e = 3 cents per kilowatt-hour (low price might be obtained for large-scale heating).

$$D_e = \frac{\times 3}{3{,}413 \times 96/100} \quad 916 \text{ cents or } \$9.16 \text{ per day.}$$

* This equivalence of units is explained in "Power Plant Testing," by James A. Moyer, 4th ed., p. 74, McGraw-Hill Book Company, Inc., New York, 1934.

CHAPTER III

ATOMIZATION OF OIL FUELS

For the efficient combustion of oil fuels it is necessary to change the liquid to a semigaseous condition, which is most easily accomplished by atomization, meaning the breaking up of the liquid drops into minute particles. A very fine, *cloudlike spray* is an example of satisfactory atomization.

Atomizers for Oil-fuel Burners.—Probably the simplest method of making a spray is by the discharge of a liquid under pressure through a plain circular orifice in the wall of a suitable tank or even from a similarly located simple cylindrical nozzle of relatively small diameter; but this discharge would be a coarse spray in comparison with the cloudlike spray that is needed for the efficient combustion of oil fuel in a modern oil burner. For this reason the atomizing devices used for oil burners are necessarily complicated and expensive.

Kinds of Atomizers.—There are two principal kinds of efficient atomizers for oil burners, some manufacturers of oil-burning equipment making burners for each kind of atomization in order to be in the market at two different price levels—the simpler equipment being, of course, usually the cheaper. The classification of atomizers is as follows:*

1. Pressure or gun types.
2. Rotary-ring or rotary-cup types.

Of these two groups the pressure type is by far the simpler as it depends for its operation mainly on the pressure effect in a nozzle. The nozzle designs that are used for the discharge of the oil fuel are intended to obtain the sort of mixing of the oil-fuel discharge with the air supply that is needed to produce satisfactory combustion.

In an oil-fuel discharge under pressure through a smooth-surfaced nozzle every particle of the oil takes a straight-line path

* The classification of atomizers in this chapter follows in a general way that of the American Oil Burner Association by Harry F. Tapp.

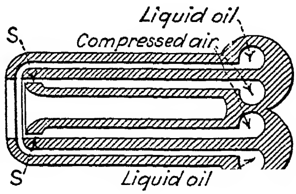
away from the nozzle tip. Such straight-line directional movement of the particles of oil fuel is in fact exactly the same theoretically as the path taken by a ball, for example, that is attached to a string held in one's hand so as to give the ball a circular movement. If the circularly moving ball is released from the hand holding the string or if the string breaks, the ball will fly off with straight-line motion.

Means for Obtaining Pressure Discharge from Nozzles.—The way the pressure for oil-fuel discharge from burner nozzles is obtained depends usually on the general type of the oil-burner installation. In large oil-burner installations as, for instance, those in industrial and marine services, the oil-fuel discharge may be from suitably designed nozzles to which the oil fuel is supplied at a relatively high pressure; the discharge pressure being commonly in this type of burner installation from 200 to 300 pounds per square inch. This pressure is obtained by discharging the oil fuel into the nozzle of the burner by a suitably designed pump. Such atomizers for high-pressure discharge may be provided with a special air-regulating device called an *air register*.

The air flow for high-pressure oil atomizers is controlled in regard to quantity, directional discharge, efficient mixing with the atomized oil, and flame shape by the combination of an air register with the high-pressure-discharge atomizer. Directional vanes may be provided in the air register (page 104) to control the shape of the flame obtained by the combustion of the oil-fuel discharge. Shutters may be provided to regulate the air supply.

In large oil-burner installations the proper oil atomization may be obtained also by admitting steam or compressed air into the shell or casing of the nozzle of the burner. In such cases, the steam is, of course, obtained from a high-pressure steam boiler, and the compressed air from an air compressor. In oil burners designed for domestic service, especially for house heating, the air pressure needed for atomization is obtained usually from a blower (page 67); or for types intended for low-pressure nozzles from an enclosed centrifugal fan. Examples of these general types will be explained in a later chapter. A simple type of nozzle for the atomization of oil fuel by compressed air is shown in Fig. 16. In this nozzle atomization is produced by the discharge of compressed air through a narrow circular slot S. The air under pressure is forced out through this narrow opening

with high velocity and in this discharge it impinges on and carries along with it droplets of oil fuel which, figuratively, are torn apart into minute particles by the high-velocity air, so that a cloudlike spray of oil fuel, mixed with air, is discharged from the nozzle into the chamber of the burner where the oil fuel is to be burned.



16.—Simple nozzle for oil-fuel atomization.

Practical experience and study of the discharge from nozzles and orifices show that the angle of the lip of the discharge cone of the orifice O in Fig. 17 is an important factor, for the reason that the angle of discharge of the conical-shaped spray will vary with the angle of this cone, a wide conical angle giving a wide conical discharge and a small angle a narrow discharge. Usually the manufacturers of oil burners specify this nozzle discharge angle according to the various sizes and shapes of the combustion chambers of furnaces or heaters to be equipped with oil burners. As a general rule, it may be stated that a long narrow combustion chamber will require a rather narrow (small angle) oil-discharge cone at O; on the other hand, a short wide combustion chamber will need a much wider oil-discharge cone. It is therefore a mistake to assume that an oil burner is improperly

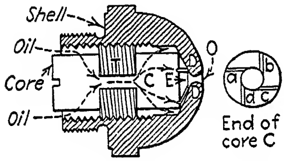


FIG. 17.—Atomizing nozzle with conical tip.

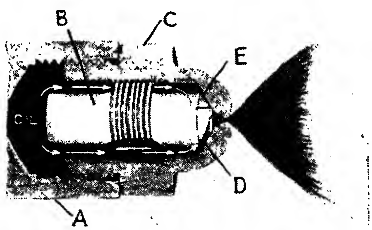


FIG. 18.—Atomized discharge of conical-tip nozzle.

designed if satisfactory combustion conditions are not obtained with the first selection that is made of a discharge cone of the type shown in Figs. 17 and 18. It happens frequently that there are

local conditions which tend to distort the flame shape to such an extent that a different discharge nozzle is needed from the one that would ordinarily be selected for the apparent conditions of operation. Often nozzle selection is a cut-and-try process.

For any service requiring the discharge of a liquid or even a gas through a nozzle, it is an important and necessary requirement

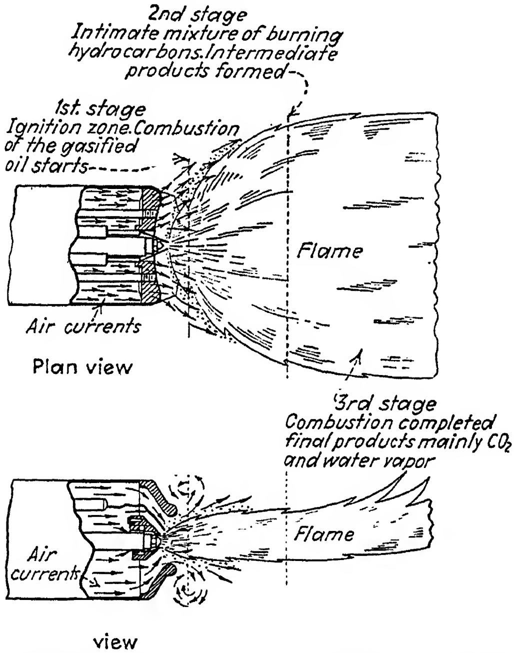


Fig. 19.—Atomizing nozzle for pressure discharge showing three stages of combustion (flat flame).

that the inside surface of the nozzle should be finished as smoothly as it can possibly be made. For this reason, in the nozzle itself, grooves or angular sections should be avoided. It is often stated that a nozzle must always be of circular shape for highest efficiency. Reliable experiments with the discharge of fluids through nozzles of various designs show, however, that a circular shape is not at all essential but that the cross section must always be well-rounded, and, therefore, a nozzle with an elliptical cross section is likely to be just as efficient as one with a circular cross section. It is unlikely, however, that oil-burner manufacturers will adopt

a section other than a circular one for the reason that elliptical or similar shapes are very expensive to construct. For the reason that the discharge nozzle of an oil burner should have a smoothly finished inside surface, special precautions should be taken in the handling and shipping of nozzles that small objects with hard surfaces do not come into contact with the discharge end of the cone D in Fig. 18 of the nozzle. Even a scratch on the conical surface of an oil nozzle will, to some extent, reduce its efficiency. There is likely to be some erosive scratching of the conical surface E of the oil nozzles that have been long in regular service; the scratching erosion is especially likely to occur when fuel oils are used that contain a considerable amount of semisolid sediment which is present in sufficiently small particles to pass through an oil strainer (page 126). When the surface of the cone of a nozzle is eroded in this way, it is profitable usually to remove the worn cone and to replace it with a new one.

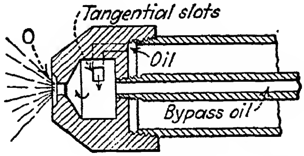


FIG. 20.—Atomizing nozzle for pressure discharge with tangential slots and by-pass for excess of oil fuel.

Three different types of nozzles for pressure discharge through a very small aperture are illustrated in Figs. 19, 20, and 21. Numerous similar designs, for the spraying not only of oil but also of other liquids, may be satisfactorily used with only minor changes. In all types of pressure atomizers, the nozzle must deliver the oil fuel as a very fine spray or mist as needed for combustion.

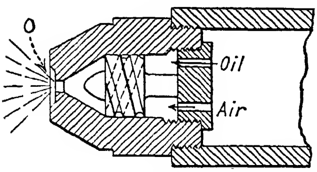


FIG. 21.—Simple atomizing nozzle for pressure discharge.

The nozzle shown in Fig. 21 is designed to produce a whirling motion on the discharge side of the nozzle in order to utilize centrifugal

and air will be delivered in very fine particles. In the case of the nozzle in Fig. 17 it will be observed that the plug or core C is screwed into the body or casing of the nozzle, so that the oil passes through the space between the core and the inside surface of the nozzle in the directions shown by the arrows in the figure. The core C, which is made slightly conical at the front end, as already explained, is fitted into place with a "ground" joint so that there is an oiltight

fit between it and the lip or front end D of the nozzle. The conical end of the core, it will be noticed, is cut off before it comes to a point so that a small conical chamber is formed just behind the orifice O. The supply of oil is discharged into this chamber through grooves

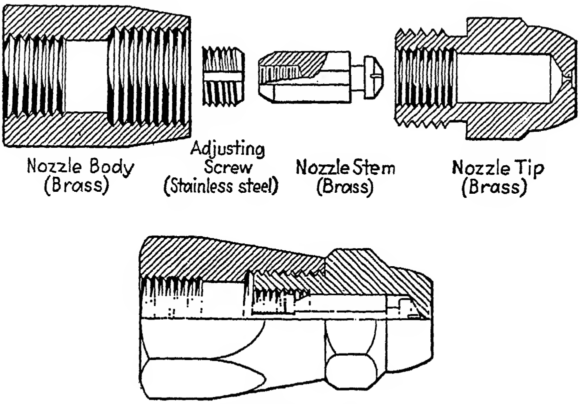


FIG. 22.—Details of typical rotary-spray atomizing nozzle.

a, b, c, and d cut into the end of the conical surface E of the core C. These grooves are shown in an end view in the figure. In this type of nozzle, the oil-fuel particles are given a rotary motion by the discharge through the tangential grooves a, b, c, and d. Then the whirling particles of oil are forced through the orifice to form a thin, conical spray for discharge into the combustion chamber into which the burner is fitted. A typical rotary-spray atomizing nozzle operating on this principle is shown with construction details in Fig. 22.

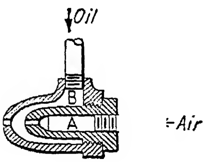


FIG. 23.—Typical oil-atomizing nozzle for medium pressures discharging mixed air and oil.

An oil-atomizing nozzle requiring only medium pressures is shown in Fig. 23, with an integral air chamber A. In this type of nozzle, air and oil are well mixed when discharged together from the orifice O.

Low-pressure Atomizing Nozzle.—A nozzle of an entirely different type from those illustrated in the last sections, and intended for a quite different method of atomization, is used in what are called low-pressure atomizing oil burners. In the nozzles of these

burners, the air required for combustion is mixed with the oil fuel inside the nozzle itself where a foamy mixture somewhat like the oily *emulsion* (page 225) that accumulates sometimes in the crankcase of an automobile when *water* and oil are intimately mixed in, being churned by the crankshaft and connecting rods of the engine. The foamy mixture of oil and *air*, instead of discharging through the nozzle under a pressure of about 100 pounds per square inch, as is commonly the case with a high-pressure-air atomizing oil burner, has in this type of nozzle only a gage pressure of about 5 pounds per square inch. As this foamy mixture discharges through the nozzle, the "bubbles" of air throughout the mixture expand suddenly or explode very much as a soap bubble does. By this sudden expansion the "bubbles" throw the oil in a thin film in all directions. This sudden expansion of the foamy mixture is caused by the sudden change in volume of the air which, being a gas, undergoes considerable change in volume for even a relatively small change in pressure.

In such a low-pressure atomizing nozzle, the mixture of oil and air passing through it occupies a relatively large volume compared with volumes handled by a high-pressure nozzle. The mixture of oil and air is discharged from the nozzle at a pressure that is very nearly atmospheric. Because of the large volumes of oil vapor and air to be handled, the orifice of such a low-pressure nozzle must be much larger than the nozzle for a high-pressure nozzle with correspondingly lower discharge velocities of the mixture. There is, however, the advantage of the low- over the high-pressure nozzle that because of the low velocities of the oil and air mixture, the *erosion effects* on the inside surfaces of nozzles and of the refractory materials of the firepot, as already noted in connection with the high-pressure nozzles (page 59), do not, to any extent, occur. On the other hand, the cost of extra equipment for the low-pressure oil burner is larger than it would otherwise be, for the reason that a suitable device, more or less complicated and expensive, must be provided to control constantly the supply of atomizing air.

Rotary Atomizing Devices.—In the classification of atomizers given on page 55, there were (1) pressure or gun-type atomizers and (2) rotary-ring or rotary-cup atomizers. As the name indicates, a rotary atomizer is one in which atomization of the oil fuel is accomplished by the rotation of a suitably shaped metal

ring or cup. A simple example of the vertical-shaft rotary atomizer is shown in Fig. 24. The atomizing cup *C* is attached to the vertical shaft *S* by means of a suitably designed spider. The armature of an electric motor *M* is rigidly attached to the shaft *S*. In the type of vertical-shaft atomizer shown in the figure, the metal cup for the oil fuel is closed at the top and the oil fuel is discharged radially in every direction through a number of orifices during the rotation of the cup by the electric motor. The discharge consists of a number of fine streams of oil, somewhat like those from a rotating lawn sprinkler.

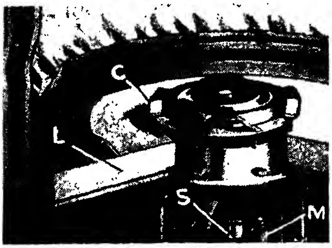


FIG. 24.—Simple vertical-shaft rotary atomizer.

In another type of vertical-shaft atomizer, a metal cup is attached rigidly to a vertical shaft, and there is a shallow trough around the edge of the cup. The fuel oil is fed into this trough and spreads out into a thin film on the wall of the cup. Then, when the cup is rotated at high speed, centrifugal force throws out the oil in a thin film at its top edge.

An atomizing device that is in principle entirely different from the last one described is shown in Fig. 25. In this device oil is

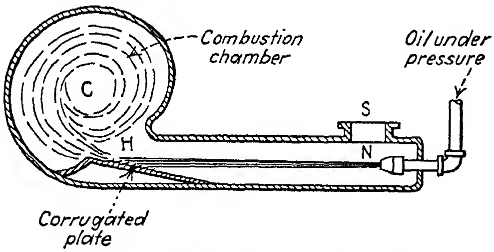


FIG. 25.—Rough-surface plate atomizer.

supplied at a high pressure and flows from the oil pipe through the nozzle *N*, so that a jet of oil is discharged at a high velocity in a straight line, without any appreciable atomization. This high-velocity oil jet is then directed against a corrugated plate *H* where the oil drops are torn apart and scattered about in all directions as fine well-atomized particles. The air required for combustion in this type of oil burner enters at the opening in the

burner casing marked S, so that a well-mixed combustible mixture of fuel oil and air is obtained in the combustion chamber C, where a suitable ignition device is provided for *starting* combustion.

Pump for Atomization.—In some types of oil burners, a method of mixing the air for combustion with the oil utilizes a rotary pump which may be somewhat like the one shown in Fig. 26 (see also page 91). This pump is usually driven by an electric motor. Both air and oil fuel are taken into the suction chamber where they are thoroughly mixed, and at the same time a coarse atomization of the oil is obtained. The mixture of fuel oil and air, as discharged from a pump suitable for this service, will have a gage pressure usually of from 3 to 5 pounds per square inch. This mixture will then be completely and finely atomized by being forced through a suitable orifice into the combustion chamber. Such a method of using a pump for oil-fuel discharge may be used to provide also, at the same time, the suction needed to draw the liquid oil fuel from the storage tank. This method, however, is suitable only for small installations.

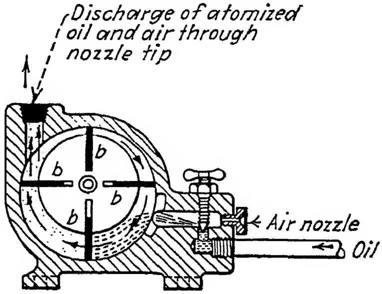


FIG. 26.—Rotary pump used for making combustible mixture of oil vapor and air.

The pump delivers compressed air together with the oil fuel, and this air is the medium used to obtain a coarse atomization.

Calculation of Velocity of Rotating Disk for Atomization.—Simple calculations of peripheral speed or "edge" velocity of a disk operated for centrifugal-force effect in a rotary burner is often necessary for the reason that, for a given grade of oil fuel and a given weight of oil to be burned, the fineness of atomization will be proportional to the velocity of the outer edge of the rotating disk.

Atomization by Rotating Disk.—The centrifugal force developed at the outer edge of a rapidly rotating disk with a cup-shaped ring or a series of orifices in the periphery of the disk can be used to break up a film of oil into minute particles. The fineness of atomization will in general be proportional to the velocity of the periphery of the rotating disk. At least this will be the case when

the cup or orifice ring from which the atomized particles are discharged is coincident with the periphery of the disk. The peripheral speed V of a disk or similar mechanical device in feet per minute can be stated in the following equation:

$$V = 3.1416 \times d \times N.$$

where d = diameter of disk at periphery of cup or nozzle ring, feet.
N = revolutions per minute (r.p.m.).

The use of this formula may be better understood if a typical example is stated here.

Example.—The peripheral speed V of a disk 8 inches ($d = 8/12$ ft.) in diameter, rotating at 3,600 revolutions per minute (N_i) is according to the preceding equation

$$V = 3.1416 \times 8/12 \times 3{,}600 = 7{,}540 \text{ feet per minute.}$$

It will be observed that the equation for peripheral speed, when solved for the value of the diameter of the disk, will read

$$d = V \div (3.1416 \times N),$$

which indicates that the diameter of the disk for the same peripheral speed, that is, for the same degree of atomization, is inversely proportional to the number of revolutions per minute (N). If, therefore, with the same peripheral speed the same degree of atomization is to be obtained with a disk which is to be operated at 1,200 revolutions per minute the diameter d would be (3,600 ÷ 1,200) × 8, or 24 inches.

In order to obtain good combustion, the particles of oil fuel must be thrown off from the periphery of the disk or from that of the nozzle ring at the periphery, so that there is fairly good opportunity for the air to mix with the oil particles. Such opportunity for the mixing of the air for combustion with the particles of oil fuel is not easily attained when the oil particles form a continuous film on the surface of the rotating disk. With the formation of a film on the disk, the air for combustion may be deflected and passed around instead of *through* the oil; and when this occurs, the combustion is incomplete and is likely to be smoky.

The rotating disk, with or without a nozzle ring, must have a smooth finish, and it is, of course, important also that it should be handled carefully in transportation for the reason that scratches or other roughness of the surface of the disk are likely to cause imperfect atomization.

Balancing of Rotating Disks.—The disks used for atomization by centrifugal effects must be carefully balanced for operation at the high speeds at which they are to run. The most important reason for this balancing is that a high-speed disk if unbalanced will, in the first place, set up vibrations which may injure the disk and especially an attached nozzle ring, if there is one at its periphery; and secondly, that such vibrations are likely to cause noisy operation. Disk vibrations in addition will be likely to cause uneven and otherwise variable discharge of the atomized fuel.

Advantages and Disadvantages of Rotary Type.—The following advantages may be listed for the rotary-disk type of oil burner (with or without a nozzle ring): (1) High efficiency when properly adjusted; (2) adaptability to the use of relatively heavy fuel oils for domestic service; (3) flexibility in the use of the same size of burner over a large capacity range.

On the other hand, these disadvantages are important: (1) Susceptibility to vibration with consequent abnormal noise and irregular and otherwise faulty atomization; (2) relatively high cost of the burner equipment; (3) inefficient combustion when the oil burner is operated far beyond its actual capacity.

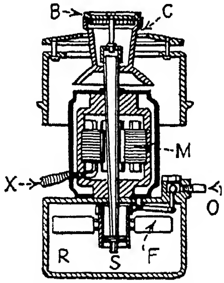


FIG. 27.—High-speed vertical-shaft atomizer operating with centrifugal force.

Examples of Typical Mechanical Rotary Atomizers.—When oil fuel is atomized by the rotating-disk method with, preferably, a nozzle ring at the periphery of the disk, the oil fuel is supplied through the pipe O and a regulating or control valve (page 129) which may be an automatic-float valve, as shown in Fig. 27. As shown in this illustration, the oil fuel is atomized by being discharged from a rapidly rotating cup C. It will be noticed that this cup is tapered, expanding from the bottom toward the top; the oil enters the cup near the bottom where its diameter is smallest. As the oil fuel is carried along, it is elevated by centrifugal force and spreads out in a thin film on the inner surface of the cup, owing to the larger diameter at the top of the cup; when it reaches the top, it is thrown off with very high velocity from its edge. The cup C is rotated by an electric motor M which is shown in the figure just below it. The rotating cup and

the motor are directly connected by being on the same shaft S which is *tapered* as shown in the figure with the smallest diameter at the bottom. This small end at the bottom extends into the oil reservoir R so that the oil is lifted by centrifugal force and

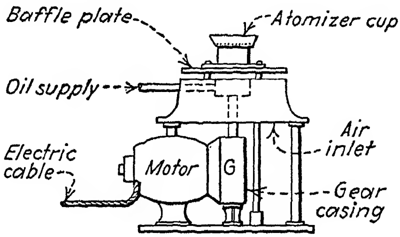


FIG. 28.—Vertical-shaft rotary atomizer (gear driven by horizontal-shaft motor).

delivered into the cup C; there it is atomized and discharged into the firepot of the oil burner, being mixed during this discharge with a small amount of air from the blades B attached to the top

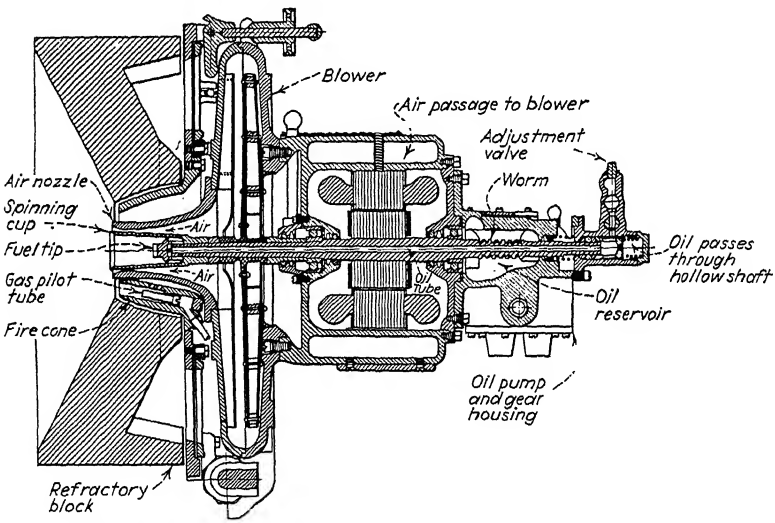


FIG. 29.—Horizontal-shaft atomizer (cup type) with centrifugal fan.

of the cup. The rest of the air that is needed for combustion enters the combustion chamber or firepot through plates around the cup designed to admit this air with as little noise as possible. The electric wires for the motor are marked X.

Another method of driving a disk-type atomizer on a vertical shaft is shown in Fig. 28. In this case, the shaft of the electric motor is horizontal, and consequently gears are needed to transmit the power from the horizontal shaft to the vertical shaft driving the atomizing disk. Since speed-changing gears are required for such a design, it makes it easy to apply in this case a low-speed electric motor instead of one designed for a high speed. The required high speed of the rotary cup is obtained by the usual method of making the gears of unequal size, the smaller gear being on the vertical high-speed shaft.

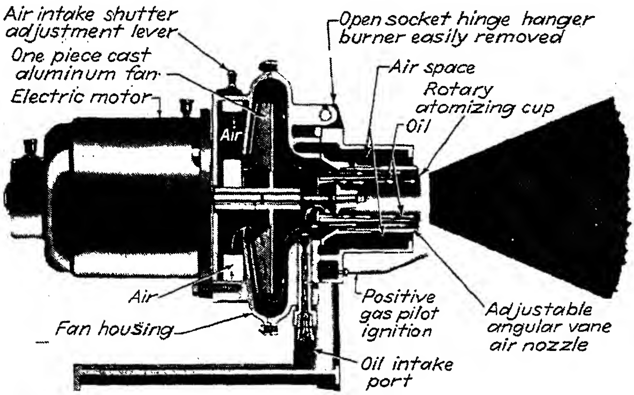


FIG. 30.—Horizontal-shaft atomizer (cup type)—adjustable air supply from fan discharge.

A rotary-cup burner having its disk set up on a *horizontal* shaft which is directly connected to a horizontal-shaft electric motor is shown in Fig. 29. The shaft carrying both the motor and the atomizing cup has also an attached centrifugal *fan-type blower*, which provides the air supply at relatively low pressure around the periphery of the cup. In the application of the rotary-cup burner shown in this figure, the oil is supplied to the oil burner by a pump driven by a worm and a gear wheel for speed reduction. A similar atomizer is shown in Fig. 30.

Still another type of atomizing-disk oil burner is shown in Fig. 31. In this case, the atomizer consists of a cup-shaped inverted cone, which flares out into a flat horizontal ring. The oil is

supplied to the center of the cup where it spreads out in a film which is projected by centrifugal force to the outer edge of the flat ring *R*. On the lower surface of the cup, there are small fan blades from which air is delivered at a low pressure into the oil film just beyond the edge of the ring *R*. The cup and attached

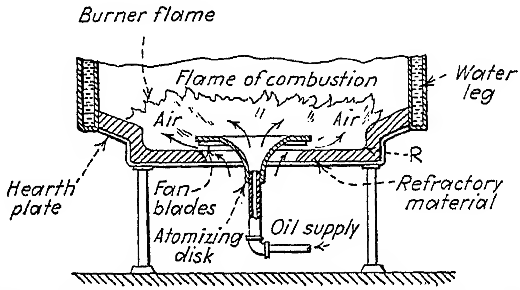


FIG. 31.—Vertical-shaft rotary-disk atomizer with fan blades to direct air supply.

ring may be driven by a directly connected vertical-shaft electric motor. A horizontal circular refractory firepot lining is provided as shown.

A so-called "atomizing head" is the distinguishing feature of the type of oil burner illustrated in Fig. 32. This atomizing head which is circular is provided with a series of orifices or what are

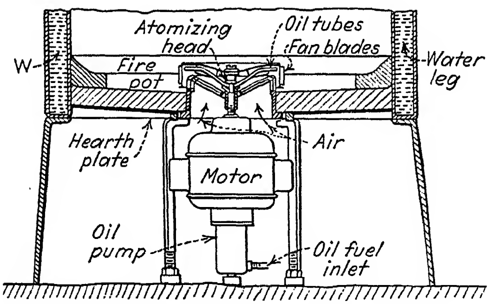


FIG. 32.—Atomizing head with orifices supplied through a hollow shaft.

sometimes called "oil tubes." In the operation of this oil burner, the oil fuel is delivered to the orifices or tubes of the atomizing head through the *hollow shaft* of the burner by the pump of which the inlet-pipe connection is shown in the figure. In the design shown in Fig. 33, the fuel oil is drawn up from the oil reservoir by

means of "picks" somewhat in the same way that a railroad locomotive takes up water from a trough between the tracks while it is in motion. The oil from these "picks" is thrown against the sides of the atomizer and is discharged through very narrow slots in the sides of the oil cup upon a refractory lining. The atomization that is obtained with this device is intended to be relatively coarse in order to prevent the flame of the burner from flashing back to the atomizing cup. Some means of directional control of the flame is necessary in order to avoid discharging the *atomized*

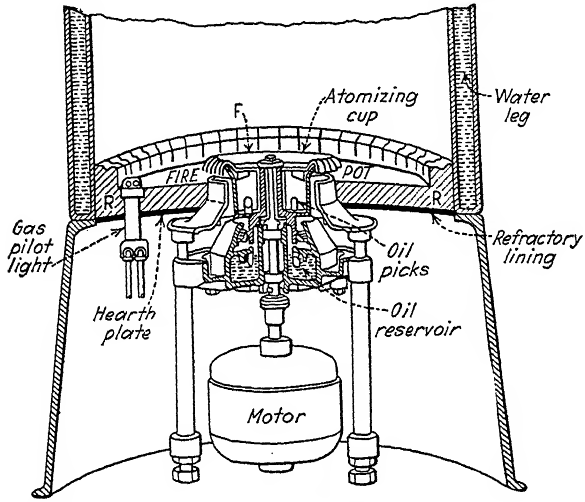


FIG. 33.—Rotary atomizer with oil picks and gas pilot light for starting combustion.

oil fuel above the ring of incandescent refractory material. The relatively coarse atomization makes it necessary, of course, that the oil fuel shall be *vaporized* when discharged upon the upper edge of the ring of refractory material. For this reason, the grade of oil fuel to be used will be determined by the relative amounts of (1) *atomization* and (2) *vaporization* that are required.

The capacity of this type of oil burner is determined by (1) the peripheral speed of the atomizer as well as by (2) the capacity of the small fan blades *F* discharging the air for combustion and (3) the diameter of the ring *R* of refractory material. This ring of refractory material must be carefully constructed in this type of burner to provide for the correct placement of the oil in the

firepot of the burner. If the diameter of the ring of refractory material is increased, the atomizer must be raised to allow for the trajectory effect of the oil-fuel discharge. Figure 33 shows the location of a gas pilot light for starting the combustion of the oil fuel.

Special Methods of Mixing Atomized Oil with the Air for Combustion.—In any type of oil burner, it is of the utmost importance to design the parts of the burner so that there will be the best possible mixture of the fuel oil with the air supplied for the combustion process. In most types of oil burners, the air for combustion and the atomized oil fuel are already mixed as they enter the combustion chamber of the burner, the object being that in this way there will be continued mixing of the oil fuel with the air during the entrance of the mixture to the combustion chamber and also as the combustion progresses.

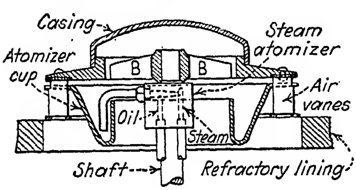


FIG. 34.—Oil atomizer with vanes for directing air supply.

One of the methods sometimes used to obtain better mixing of the oil fuel with the air for combustion depends on the use of *directional vanes* in the air-supply pipe very much as in Fig. 34. Another method, the *cross-flow method*, is to design the parts of the burner so that the air for combustion passes upward through the flame in the firepot, as, for example, in the burner shown in Fig. 92 (page 136).

Classification of Methods of Mixing Oil Fuel and the Air for Combustion.—The methods of mixing the atomized oil fuel with air, as required for combustion, may be classified into three groups: (1) cross flow; (2) counterflow; and (3) combination of cross flow and counterflow.

In the *cross-flow system*, the atomized oil fuel is discharged from a nozzle or a similar device at an angle (usually 90 degrees) to the direction of the flow of air. In the *counterflow system*, the atomized oil fuel and the air for combustion are discharged from opposite directions. In Fig. 35 is shown the counterflow method of mixing by the horizontal discharges of both the oil fuel and the air for combustion. In other words, these discharges meet each other "head on." In the same figure there is illustrated the cross-flow method by the arrows indicating air and oil flows that

are marked *a* and *b* in the illustration. These arrows intersecting near the edge of the firepot do not, of course, meet each other at right angles (90 degrees), but at an angle so much smaller than 180 degrees to warrant their being taken to represent "cross-current flow." There has always been a difference of opinion

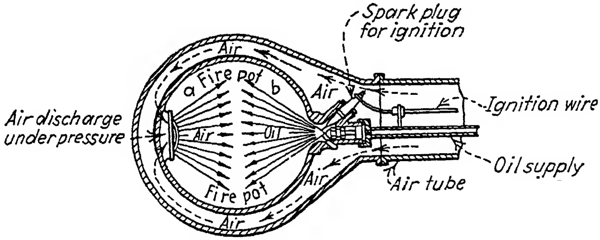


FIG. 35.—Counterflow method of mixing atomized oil fuel with air.

among designers of oil burners as to which of these systems is to be preferred, or whether the *combination* system (illustrated in Fig. 36) is the better. Practically all designers agree that *turbulence*—the thorough mixing of the atomized oil fuel with the air for combustion—is desirable; but how this turbulence is best

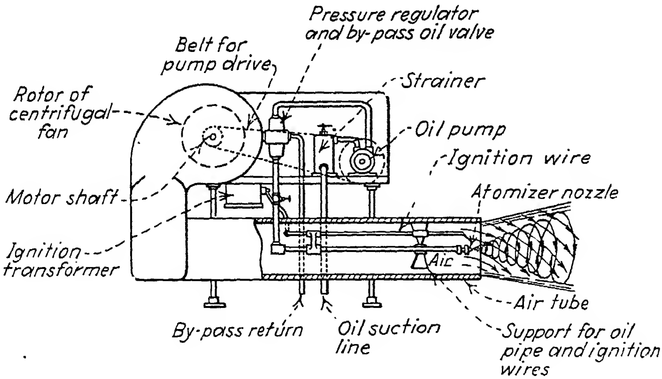


FIG. 36.—Combination of cross-flow and counterflow methods.

obtained is always a matter for discussion among engineers, some claiming that the cross-flow principle gives the better results, and others claiming that the counterflow method is always preferable.

A practical example of an oil burner using the *combination* of cross-flow and counterflow mixing of the atomized oil fuel with the

air for combustion is shown in Fig. 36. It will be noticed that this oil burner is provided with a centrifugal fan driven by an electric motor not shown in the figure; the motor and the fan are on the same shaft. At the end of this shaft is a pulley which operates by means of a belt drive the oil pump at the right-hand side of the figure. The centrifugal fan on the oil burner supplies the air needed for combustion at a pressure of a few ounces per square inch. The shape of the fan discharge gives the air a rotary motion which is used in this apparatus for obtaining exceptionally good mixing, thereby effectively combining the atomized oil fuel with the air in the combustion chamber. The slow, even low-pressure flow of air into the combustion chamber makes it

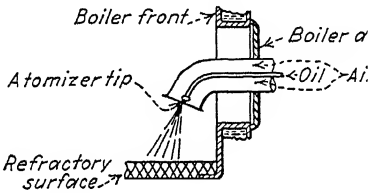


Fig. 37.—Application of downshot atomizer for turbulence.

possible to operate an oil burner of this type so that very little noise is produced by combustion.

A somewhat different method of mixing, but also with the object of producing turbulence, is shown in Fig. 37. In this case, the atomized oil fuel is discharged near the end of an air duct which carries air for combustion from a centrifugal fan not shown in the figure. The air enters the combustion chamber at a relatively low pressure. In this case, both the air for combustion and the atomized oil fuel are discharged downward in practically parallel directions. During the downward flow of the atomized oil fuel and the air for combustion, there is considerable mixing, but real turbulence results only after both the air for combustion and the atomized oil fuel have reached the refractory surface underneath, which is shown in the figure. The discharge of the atomized oil fuel in this downward direction gives the name "downshot" to this kind of burner. Not all such downshot oil atomizers are provided, however, with the air for combustion under a slight pressure, as, for example, from a centrifugal fan. In some cases, the air for combustion is discharged in an upward

direction into the firepot from slots in the firebox, so that turbulence is obtained by the discharge of the atomized oil fuel and the air for combustion in very nearly opposite directions, so that nearly *counterflow* conditions are obtained. A commonly used downshot oil-atomizing burner is shown in Fig. 38.

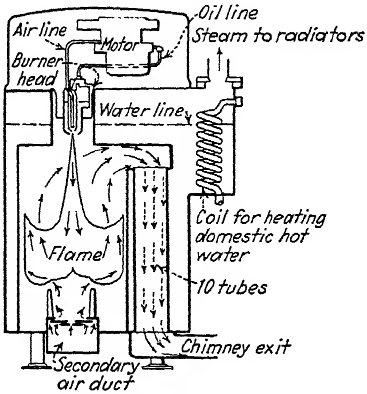


FIG. 38.—Domestic type of downshot oil atomizer as installed in special boiler.

Another type of oil atomizer intended mainly for industrial and marine services is shown in Fig. 39. This type of atomizer is especially suited to a requirement that a relatively flat flame should be provided. It will be noticed that there is a flexible connection between the levers controlling the oil fuel and the "mixing" air for combustion, and the control levers on the air shutters; the extra air not actually needed for mixing the atomized oil fuel with the air for combustion being admitted through the adjustable air shutter at the supplementary air intake *I*.

Another example of the use of a supplementary air supply for combustion is shown in Fig. 40. In this case, the supplementary

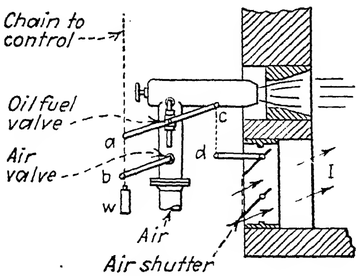


FIG. 39.—Flat-flame atomizer for industrial services.

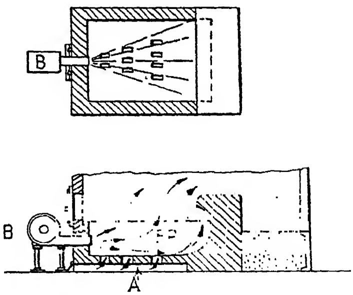


FIG. 40.—Atomizer with supplementary air supply in firepot.

air supply, which may be under pressure or without pressure, is distributed through a shallow boxlike chamber *A* through holes in the material used for the bottom of the firepot *FP*. Since a centrifugal fan or low-pressure blower *B* is used to discharge the

combustion mixture into the firebox, it is desirable to bring in some air in that way, so that the air coming through the holes in the bottom of the firebox must be necessarily a supplementary supply.

Stationary Guide Vanes for Directing Air Supply.—In some types of oil burners that operate with a rotating nozzle cup, stationary guide vanes are sometimes attached on the casing of the fan or blower with the object of giving to the air entering around the rotating nozzle cup a direction of rotation which is opposite to that of the cup. Because of this opposite flow of the atomized fuel oil to that of the air, an unusually good mixing of the oil particles with the air for combustion is obtained. By varying the angle of these guide vanes, the shape of the flame can be altered to some extent, according to the shape of the combustion chamber or firepot of the oil burner. A similar flame distribution is shown pictorially in Fig. 41.

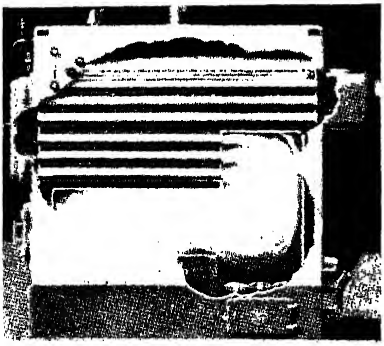


Fig. 41.—Pictorial view of operation of atomizer in Fig. 40.

Compressed Air and Steam for Atomizer Operation.—Domestic oil burners do not often have atomizers that are operated by compressed air or by steam, for the reason that compressed air (at a sufficiently high pressure) and steam are not easily available for use in the heating equipment of *houses* in which oil burners are commonly used. For industrial, marine, and locomotive services where both dry steam and compressed air are usually available, atomizers operated by steam or compressed air are not uncommon. On the other hand, it should be noted that the domestic oil burners that have been designed for use with steam atomizers have not been satisfactory, and the same may be said of atomizers operated by compressed air for domestic oil burners. The reasons for their failure are about the same: (1) The common difficulty with combustion noise, which is largely accentuated by the operation of a high-pressure atomizer whether air- or steam-operated; (2) complexities of steam generation at a pressure high enough for such nozzle operation; and

(3) the expense of air compressors that are suitable for supplying air at a sufficiently high pressure.

Air Requirement for Low-pressure Atomizers.—When light fuel oils are to be atomized, the breaking up of the particles of such a fuel oil into a spray can be accomplished quite satisfactorily with the air under only a slight pressure and no pressure on the oil; the only qualifying condition is that a sufficiently large quantity of air must be supplied. Obviously, on the basis of energy equivalence, a much larger quantity of air at low pressure will be required for the atomization of a given quantity of oil than would be needed for the same grade of oil at a higher pressure.

The minimum quantity of low-pressure air required for the atomization of an oil fuel is given in Table IX. It should be noted that in this case the emphasis is on the word *minimum* as the actual quantity of low-pressure air required depends to a large extent on the design of the burner and especially on the grade, temperature, and pressure of the oil fuel. The table, however, is useful in giving some idea of the minimum air requirements for average practice.

Table IX.—Minimum Amount of Air Required for Fuel Atomization in Low-pressure Nozzles

Air Pressure, Pounds per Square Inch (Gage)	Air for Atomization in Per Cent of Air Required
0.25	65
0.50	50
1	40
2	30
5	22
10	17
25	12
60	8
100	5

An effective means of using low-pressure air, as it might be supplied by a ventilating fan, preferably of the turbine or sirocco type (page 337), is shown in Fig. 42. In this type of burner, the oil is discharged through a pipe from the storage tank, as shown in the figure, to a constant-level device from which it is lifted by the suction produced by the air discharge through the venturi tube (page 135) located centrally in the air duct. The oil is atomized as it enters the throat of the venturi tube *V* from the

vertical suction pipe S. The mixture of atomized oil fuel and air for combustion is carried along with the flow of air, including an excess amount, into the combustion chamber of the oil burner.

A typical example of an atomizing device operated by low-pressure air is shown in Fig. 43. In this device, the oil is supplied

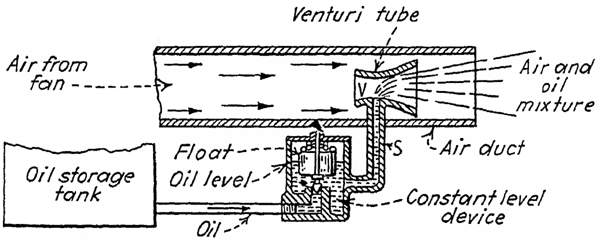


FIG. 42.—Venturi-type of oil atomizer with constant-level device.

to the burner from the discharge end of the venturi tube at D; the action of the venturi tube is made possible by the flow of low-pressure air from the left-hand portion to the right-hand side of the figure. The air flow in the duct for the operation of a burner of this kind will require a gage pressure of from 1 to 2 pounds per square inch. The oil fuel as discharged from the mouth of the venturi tube at D is only coarsely atomized so that further and finer breaking up of the particles of oil fuel is necessary, and this is accomplished by the air that passes around the edge of the venturi tube at e, e. This type of burner is not well suited for domestic oil burners but is sometimes used in large oil-burning installations.

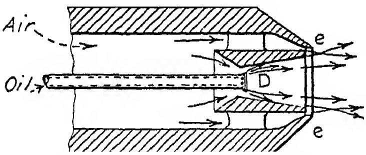


FIG. 43.—Low-pressure oil atomizer with venturi tube for coarse atomization.

For the atomization of heavy types of oils in commercial and industrial installations when steam is used instead of compressed air a pump would not be needed, as the steam is obtained from the boiler at the required pressure. In this connection, it should be noted that in all types of atomizing burners for services similar to those explained here, when steam is substituted for compressed air as the atomizing means, the same quality of atomization can be obtained at a considerably lower pressure.

Steam Atomizing Devices.—Typical steam atomizing devices are shown in Figs. 44 and 45. Both of these types are intended to produce fan-shaped flames. The first of these atomizing nozzles is a so-called "outside" mixing device, and the second an "inside" mixing device. The difference in the operation of these two types may be clearly seen from the study of the figures. For either type the oil-regulating valve is usually set for a gage pressure of somewhere between 20 and 50 pounds per square inch.

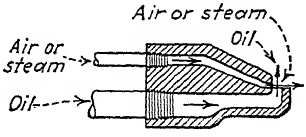


Fig. 44.—Outside mixing atomizer for compressed air or steam.

Quality and Amount of Steam Used.—For the reason that moisture in the steam used in an oil-spray nozzle is likely to cause sputtering of the flame in the combustion chamber, only dry or superheated steam should be used. Some types of steam-operated oil-atomizing nozzles require a larger amount of steam than others, but in most cases the percentage of the steam output of a steam boiler that is used for the oil-atomizing device will depend more on the carefulness of the person tending the boiler than on

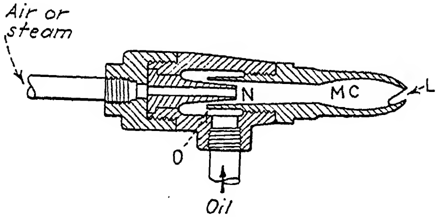


Fig. 45.—Oil atomizer to produce turbulence in inside mixing chamber.

any other factor. It may be stated as a general rule that the nozzles for supplying oil fuel to a well-designed boiler, if carefully adjusted and operated, will require between 1 and 2 per cent of the boiler capacity for their operation, while on the other hand, if the operation of the steam nozzles is not in good hands and if the nozzles are poorly designed for the particular conditions of service, the nozzles for oil atomization may take from 4 to 6 per cent of the boiler capacity.

An "outside" mixing atomizer like the one shown in Fig. 44 is in common use in industrial installations and may be used with either compressed air or steam without change in the design. In

the operation of this atomizing device, the oil fuel flows with little velocity from the rectangular oil-fuel orifice. Just beyond this orifice, high-velocity steam or compressed air impinges on it, the steam or air moving in this case at an angle of 90 degrees to the direction of flow of the oil fuel. By this impinging of the steam or compressed air on the oil, it is broken up into fine particles which are then discharged well mixed with air as a fan-shaped spray into the combustion chamber of the oil burner.

The "inside" mixing type of oil atomizer, which also is suitable for operation with either compressed air or steam at moderate pressure, is shown in Fig. 45. In this type of apparatus, a certain amount of *turbulence* (page 38) is set up in the mixing chamber *MC* at the discharge end of the nozzle by the compressed air or by the steam, either of which under the conditions of service in this atomizer will break up the droplets of oil fuel into fine particles, which will then be forced through the orifice at the tip of the nozzle into the combustion chamber provided for the oil burner.

Cleaning Plugged Atomizers.—When an atomizer appears to be plugged, it can usually be cleared by blowing steam through it. A steam connection should be provided for that purpose. The best practice, in general, is to remove the plugged tips and spirals of an atomizer and immediately put them into a pan of kerosene, to be cleaned as opportunity permits.

CHAPTER IV

OIL BURNERS

Figure 46 shows the layout of an oil-burning system including a pressure- or gun-type of burner, and an oil-storage tank that is located underground at the side of the building. Frequently, however, the oil-storage tank is located in a basement room or some other place within the building, which is, of course, a cheaper

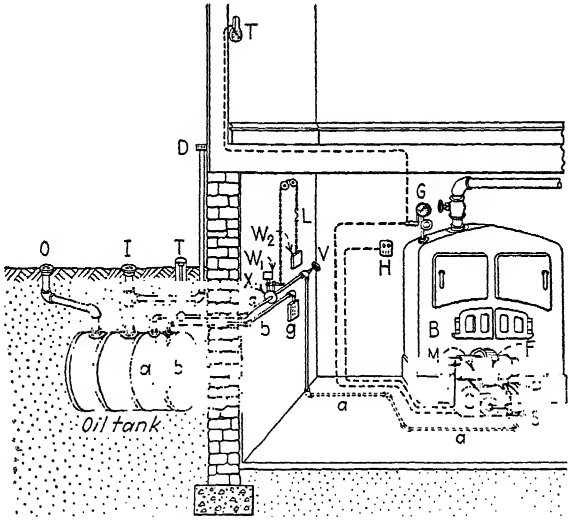


FIG. 46.—Layout of oil-burner system in basement room.

method of installation, as the trench work necessary for an outdoor storage tank can be avoided.

In the figure the oil-storage tank is shown at the left-hand side of the figure. Vertical pipes that enter only as far as the top of the oil tank are marked *O* and *I*. The pipe *O* has usually a screw cap that can be removed for filling from a tank wagon. The pipe *I* with its top at the ground level, has also in many cases a screw or hinged cap for quick removal. This pipe is used for the insertion of a measuring or gage stick of which a calibration

should be available, so that the oil contents of the tank may be determined by the scale reading on this stick. This pipe *I* can also be used for cleaning when a hose is inserted so that its lower end is near the bottom of the tank and its upper end is attached to a hand pump.

A vertical-vent pipe *D* which is always open extends alongside the building above the snowline; it is intended for the escape of air from the tank when oil is entering through the filling pipe *O*, and for the entrance of air as oil is removed from the tank by the operation of the oil burner. It provides also for the expansion and contraction of the air through temperature changes. The oil piping marked *a*, *a*, *a* is connected at one end to the oil pump *P*, and at the other it enters and extends down to the bottom of the oil-storage tank. Through this pipe the suction of the pump *P* draws oil from the storage tank to the oil burner in the steam-heating boiler *B*. In this pipe line there is a hand-operated shut-off valve *V*, a safety shut-off valve *X* (weight-operated) which is held in the open position when the weight W_2 is greater than W_1. In the chain supporting the weight W_2 is a fusible link *L*, which in case of fire, melts and drops the weight W_2, thus closing the safety shut-off valve *X*. Connected with this oil piping is also the underground valve to which the valve handle *T* is attached. By turning this handle, a person on the outside of the building may, in case of fire, shut off the flow of oil into the building, where if a sufficiently high temperature is developed the oil fuel might be set on fire so as to add greatly to the seriousness of the conflagration.

A device at the top of the boiler *B* and connected to the pressure gage *G* shuts off the electric current supplied for the operation of the motor-operated pump *P* and the fan *F*, if the pressure in the boiler becomes dangerously high.

The small-diameter pipe *b*, *b* extends also at one end to the bottom of the oil-storage tank and is attached at the other end to a gage *g* which indicates conveniently indoors the depth of oil in the storage tank. It operates by fluid pressure in much the same way as one type of gasoline gage that is usually connected to a dial on the instrument board of an automobile.* In a pump-

* The operation of this type of fluid gage is explained in "Gasoline Automobiles," by James A. Moyer, 4th ed., p. 155, McGraw-Hill Book Company, Inc., New York, 1932.

operated system there should be a by-pass pipe to carry the overflow from the pump back to the oil-storage tank. When a gravity oil-feed system (page 84) is used, overflow piping is not needed.

The main switch is at *H*, through which electric current is supplied for the operation of the motor *M* and the ignition transformer *C*. An oil strainer *S* is in the oil piping as shown to remove dirt, sediment, or other foreign matter from the oil fuel.

The operation of the electric motor and consequently of the pump, fan, and ignition system is regulated for on-and-off service

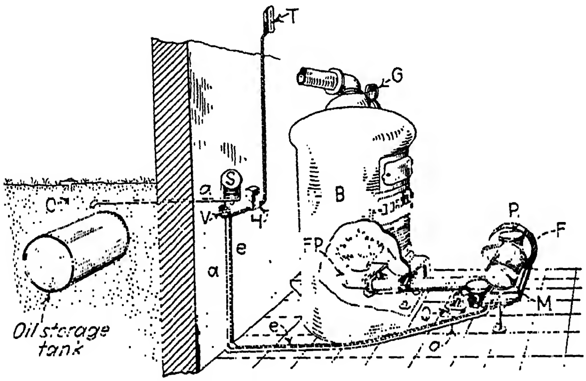


FIG. 47.—Simplified oil-burner system.

by the automatic-temperature-control device *T* (thermostat). The burner nozzle is not shown in the figure.

A much simpler oil-burning system than is shown in Fig. 46 is illustrated in Fig. 47. Here again a steam-heating boiler *B* is equipped with a pressure or gun type of oil burner. There is an underground oil-storage tank connected by the piping *a, a, a* to the oil pump *P* for distributing oil fuel under pressure to the oil nozzle *N*. There is a hand-operated oil-pressure-regulating valve *V*; and a safety overflow (page 128) *Q* is shown in some detail. The main switch is at *H*, the thermostat at *T*, the electric motor at *M*, and the cable *e, e* connects them as shown. The pipe *O* has a cap which is removable for filling the oil-storage tank. The electric motor drives the pump *P* and the fan *F*. The firepot of the burner is at *FP*.

Electric Motors for Operating Oil Burners.—For oil-burner service it is desirable that the electric motor should be of the

constant-speed type. It should be quiet in operation and should be so designed that it will not require an excessively large starting current. It is desirable also that adequate provision be made so that the motor will not cause sparking that would interfere with satisfactory operation of radio-receiving sets that may be in rooms nearby. There are still some places where direct current at about 110 volts is the only available source of supply of electric light and power. Generally, however, single-phase alternating current is available for operating the electric motor of an oil burner. This alternating current is usually supplied at from 110 to 115 volts and at a frequency of 60 cycles per second.

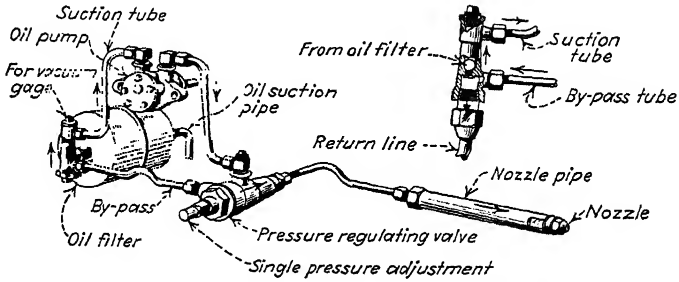


FIG. 48.—Details of typical oil-fuel piping system.

Because of the possibility that the electric-current supply may not be single-phase alternating at 110 volts and at 60 cycles, it is very important to investigate the kind of electrical power that is available before an order is given for the installation of an electrically operated oil burner.

The oil-fuel-supply circuit for a typical oil burner is shown diagrammatically in Fig. 48. The important parts are plainly marked.

Combustion in Oil Burners.—The small particles of an oil-fuel spray as discharged from an efficient atomizer in an oil burner must be heated to a high temperature by some kind of kindling flame, such as, for example, a long electric spark or a gas pilot light. However, the need of the flame of an electric spark or pilot light is only temporary. It is required only to start the combustion. The refractory walls of the firepot maintain automatically efficient combustion thereafter, by the heat radiated from these walls. Briefly stated, in most oil burners

the atomized oil fuel is discharged as a spray or cloudlike mist into contact with hot refractory surfaces.

The terms *atomizing* and *vaporizing* as used in connection with the design of oil burners are not wholly distinctive as nearly* every efficient vaporizing burner must, of necessity, incorporate in its design provision for atomization of the liquid oil fuel. The distinguishing feature of all atomizing and vaporizing oil burners must, therefore, be taken more or less generally to indicate the relative prominence in the fundamental design of "atomizing" and "vaporizing."

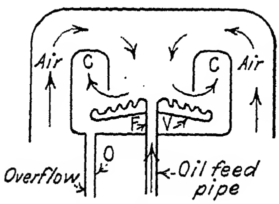
Vaporizing Oil Burners.—A so-called "pot" type is probably the best known of the various kinds of vaporizing oil burners. In this type, oil and air are delivered into a metal box or pot which is open at the top.† Starting a strictly vaporizing burner is not automatic as in the case of the oil burners that have already been described. The general method of operation is that just before starting, the pot is heated by external means sufficiently to vaporize some oil, so that combustion on a small scale may begin. After the pot has been heated by this flame to such an extent that ignition of the oil fuel can take place, the metal of the pot, or in some cases a lining of refractory material, is quickly heated to a high temperature so that the oil discharge will be vaporized as soon as it strikes the surface of the pot. After these preliminaries combustion will automatically continue in the pot as long as the supply of oil fuel is continued. Ordinarily, in such a device air is discharged by a suitable centrifugal fan (page 67) in order to produce some atomization of the oil fuel before it impinges on the heated surfaces of the pot. For the initial ignition in this type of oil burner, usually a small gas flame is used as a pilot light. This gas pilot light keeps the pot warm at those times when heat is not needed from the oil burner and an "expanded" gas flame (started according to the well-known method of pilot and expanded flames in the ordinary gas-fired hot-water heaters) may be used to provide a larger heating surface than could easily be obtained by means of an *electric* device.

* There are oil burners that operate by vaporization only, that is, without previous atomization, as shown in Fig. 51.

† Some special forms of the pot type of vaporizing burner have other than simple geometric shapes with, in some cases, openings for the discharge of the flame through one of the sides.

A vaporizing burner of this type may be provided with a very simple combustion-control device. By this control method, if for any reason the ignition system does not operate or the flame does not develop, the unburned oil is delivered to a *trip bucket* (page 85) which is supported by a lever connection. As soon as a predetermined weight of oil has collected in this trip bucket, its weight will be sufficient to close a valve which shuts off the supply of oil fuel.

Vaporizing burners are not well suited to burn the heavier oil fuels for the reason that they are likely to contain hydrocarbons which will not resist cracking (page 12) before they reach the vaporizing temperature. When a large drop, or even a film, of oil comes into contact with the hot metal of the pot, the cracking is likely to occur in that part of the drop of oil which is nearest the highly heated surface, and in that case the rest of the oil in the drop forms a blanket between the solid products that result from cracking and the air, so that solid carbon is deposited in an unburned condition on the surface of the pot. Accumulation of such layers of solid carbon on the inside surface of the pot will very soon interfere with the proper operation of such a vaporizing burner.



G. 49.—Diagrammatic sketch of simple oil burner.

One of the first successful oil burners for domestic service is shown in Fig. 49. A burner of this kind is ordinarily used in a heater or boiler that has previously been used for burning some kind of solid fuel on grate bars suitably supported in the furnace. The burner is set in the center of the grate, and the portion of the grate not covered by the burner is closed up by putting cement mortar in the openings or slots in the grate. This is done to permit air to enter the firepot or furnace only through the air passages in the casing of the burner, as shown in Fig. 50. In this way, the flow of air into the burner is controlled and the air is *preheated* (when the burner is once heated) before it is mixed with the oil fuel in the burner. The oil fuel is supplied through the oil-feed pipe from the oil-storage tank shown at the right-hand side of the figure. In this case, the oil-fuel tank is located sufficiently high above the top of the vertical oil-feed pipe in the burner that *gravity flow* (page 81) is satisfactory. In some

municipalities, gravity flow for the oil-fuel supply is not permitted, and a pump must be used in this supply line whether or not a gravity flow could be used. In every oil burner a regulating valve (page 65) is needed in the oil-feed pipe for adjusting the rate of oil flow, and in every case where a large storage tank is used a *safety shut-off valve* is also required. If for any reason the combustion of the oil fuel in the burner should be stopped when oil fuel continued to discharge from the top of the oil-feed pipe, this oil fuel would be drained from the burner through the overflow pipe and would collect in the *trip bucket*, which when partly filled, will move downward and carry with it the right-hand end

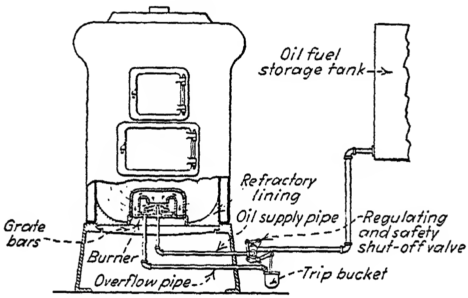


FIG. 50.—Simple step-cone oil burner with auxiliary equipment.

of the lever connected to the top of the bucket. It will thus release a tripping lever on the safety shut-off valve which closes and stops the flow of the oil fuel from the storage tank.

In the operation of this simple burner, the oil discharges from the top of the vertical oil-feed pipe and flows in a thin film over the surface of the vaporizing step cone shown in Fig. 49. This step cone is *preheated* before the burner is started and remains hot from the heat of combustion while the burner is used. By these two methods of heating, (1) when starting the burner, and (2) when the oil fuel is being burned, there is constant and effective vaporization of the oil fuel on the step cone. The vaporized oil fuel is mixed, in proper proportions for efficient combustion, with the preheated air supply which discharges as shown by the arrows in a downward direction upon the step cone.

The vaporizing burner shown in Fig. 49 illustrates the method of vaporization of the oil fuel on a hot cone or plate. A design somewhat similar to this in principle is the burner shown in Fig. 51

in which the vaporization occurs on a "hot-spot" plate. In this burner, the oil fuel discharges in drops from the pipe *O* upon the vaporizing plate *V*. This plate is kept constantly at a temperature high enough for the vaporization of the oil by the gas pilot flame *G*, to provide for quick and reliable starting. Neither of these two burners can be used for the satisfactory control of temperature in a heating system.

The fact should be added here that the vaporizing type of oil burner has been almost wholly displaced by the atomizing type. The principal difficulty in the operation of the vaporizing type is the practical impossibility of satisfactorily regulating the flame. At any rate, this type is not well suited to the intermittent and automatic operation of the so-called domestic types of oil burners.

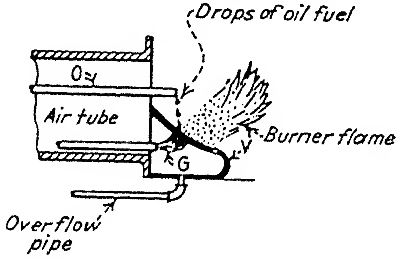


FIG. 51. Hot-spot vaporizing oil burner.

Pressure and Rotary Types of Oil Burners.—The *atomizing* kind of oil burner may be divided again into (1) *pressure* or gun type, and (2) rotary-ring or rotary-cup type, this subdivision referring to the kind of atomizer used (page 55).

In the *pressure* or *gun type* of atomizer the oil fuel is delivered through a suitably designed small nozzle (or nozzles) under pressure, so that the discharge of oil fuel is a fine spray or cloudlike mist. In fact an oil-fuel nozzle that is operated at moderate or high pressure in an oil burner produces an oil spray in very much the same way as a spray is made by the pressure in a city water main when discharging water through the nozzle of an ordinary garden hose.

In the rotary-ring or rotary-cup type of atomizing burner (also called a *rotary*-disk burner) the oil fuel is discharged at high velocity by centrifugal force from a rapidly revolving cup or similar container which has usually a large number of discharge

openings in a surrounding and attached ring. The high-velocity oil fuel is discharged first against a "pilot-light" device, as for example, a long electric spark or a gas torch, to produce sufficient combustion of the oil fuel to heat to incandescence the refractory surfaces of the firepot; but when the latter are sufficiently heated, combustion becomes automatic.

DOMESTIC OIL BURNERS*

Pressure-atomizing Oil Burners.—A typical *atomizing* oil burner operating on the *pressure* principle is shown in Fig. 52.

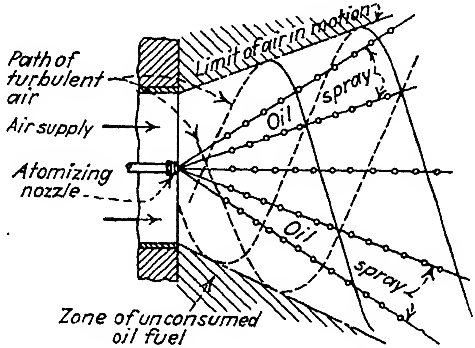


FIG. 52.—Oil fuel and air distribution in typical pressure-operated atomizing burner.

The atomizing nozzle is plainly marked. This figure is intended to show the heat distribution produced by the turbulence or eddying of the air supply, with respect to the zone of unconsumed particles of oil fuel. Turbulence in a practical type of oil burner of the pressure type is shown well in Fig. 53. At this point it may be advisable to refer to Figs. 13 and 14 (pages 50 and 51).

Figure 53 shows the centrifugal fan F, the air intake I, the stationary turbulence blades B, the ignition electrodes E, the electric cable C, the oil-supply pipe O, the oil strainer S, the oil pump P, and the by-pass valve (page 130) R. The directions of flow of oil and air are shown by the arrows.

Rotary-shaft Oil Burners.—Rotary oil burners are classified according to the position of the rotating shaft carrying the cup or ring from which the atomized oil is discharged as (1) horizontal-

* The classification of oil burners in this chapter follows in a general way that of the American Oil Burner Association, by Harry F. Tapp.

shaft atomizing burners, and (2) vertical-shaft atomizing burners. The more commonly used of these rotary burners is the one with a

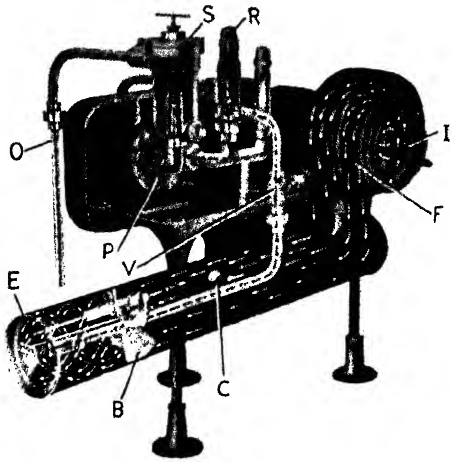


FIG. 53.—Oil and air flow with turbulence in air tube of oil burner.

vertical shaft which rotates the atomizing device by means of the attached armature of an electric motor.

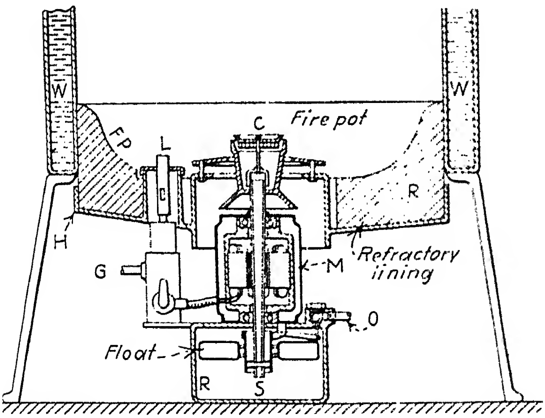


FIG. 54.—Vertical-shaft oil burner with auxiliary equipment.

A typical example of the *vertical-shaft type* of oil burner is shown in Fig. 54. An atomizing metal cup C is driven by the vertical

shaft S by means of a suitably designed motor which is direct-connected to it. Ignition of the atomized oil fuel is started by the gas pilot light L. Through the pipe G, gas is supplied for the initial ignition of the oil fuel. Between the so-called "water legs" W of the firepot FP and the centrally located oil-burning device is a layer of firebrick which when sufficiently heated serves as the hot refractory surface for automatically continuing combustion. The metal atomizing cup is closed at the top and the oil fuel is sprayed radially from orifices or short tubes in a ring around the top circumference of the cup.*

As a rule, in the vertical-shaft types of atomizing oil burners, there is a nearly horizontal metal plate H, called the "hearth-support plate," which is attached on the inside to the frame of the burner and on the outside to the side walls of the furnace so as to completely separate the lower section from the firepot, except in the center where a narrow space is left which serves as a passage for the necessary air supply of the burner. The bottom of the firepot is usually made of plastic refractory material which is built up on the hearth-support plate. The upward current of air in the narrow passage between the hearth-support plate and the burner mechanism serves as an excellent means of heat removal for keeping the parts of the oil burner at a relatively low temperature. In general, it may be stated that the main difference between the various designs of vertical-shaft atomizing burners is in the method of mixing the oil fuel which, in every case, is thrown out from the central metal cup by centrifugal force in an atomized condition to be mixed with the air required for the combustion.

The foregoing descriptions of vertical-shaft atomizing oil burners apply very well to the general type and therefore to those that are most often used. There are, however, some variations which will now be noted. In one vertical-shaft atomizing burner, the air required for combustion is supplied in a somewhat different way from the general method. In this kind of burner, the *air* for combustion is drawn up through the film of oil that has been formed on the side walls of the fuel-oil cup and passes out with this atomized-oil film between the edge of the cup and a so-called "atomizing-cup covering plate" C (Fig. 54). This is a horizontal

* The oil is forced upward by the centrifugal force developed in a hollow shaft of constantly increasing diameter from the bottom to the top.

metal plate mounted slightly above the atomizing cup. In this design, therefore, a narrow slot is left between the upper edge of

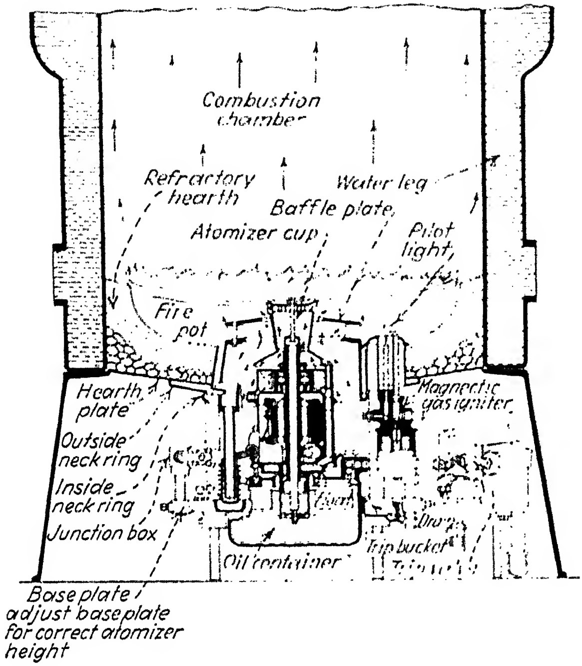


FIG. 55.—Details of commercial gn of vertical-shaft centrifugal-type oil burner.

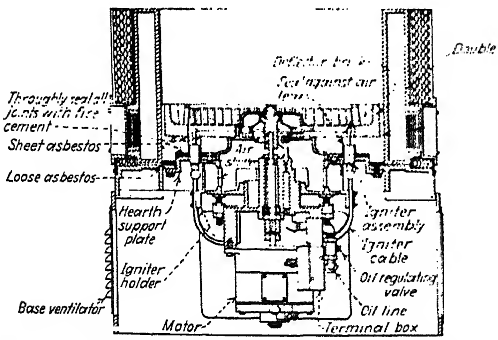


FIG. 56.—Firepot and burner of vertical-shaft rotary oil burner.

the cup and this plate. Most of the air for combustion in this type is discharged, however, through "air deflectors," which are

located below the burner proper, the air discharged from them being merely supplemented by the air supplied through the slot along with the oil film. The tapered hollow shaft *S*, with its largest internal diameter at the top, utilizes centrifugal force to raise the oil film to the top of the shaft.

A somewhat similar design showing more details is illustrated in Fig. 55. Still another design of a vertical-shaft rotary burner is shown by Figs. 56 and 57.

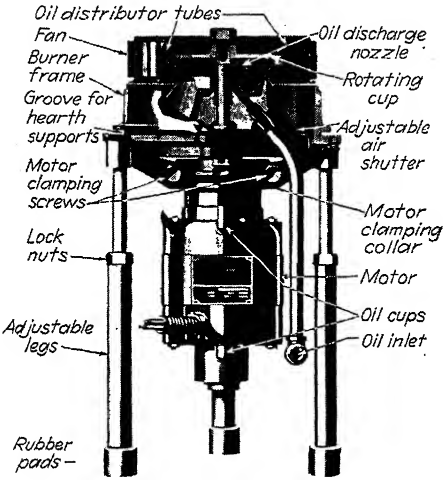


FIG. 57.—Exterior view of typical vertical-shaft rotary burner.

In still another design, the general arrangements are somewhat like those in Fig. 54, with the exception that a fan with short "turbine" blades (page 337) is firmly attached to the vertical shaft of the burner so that the blades of the fan surround the atomizing cup. The air is drawn up around the cup and meets the oil fuel before passing through the blades of the fan. In this case, the turbulence, or eddying set up by the blades of the fan, serves to improve the completeness of mixing of the atomized oil with the air. There are numerous other arrangements, some admitting the air for combustion above and others admitting it below the oil cup.

A movable-blade type of pump (see also page 63) is shown in Fig. 58. This pumping device serves for "metering" the air

supply and for mixing the oil fuel with the air required for combustion.

A typical pressure-atomizing burner is shown in Fig. 59. It is operated by a horizontal-shaft electric motor which drives the squirrel-cage centrifugal fan and the oil pump. The oil line, oil

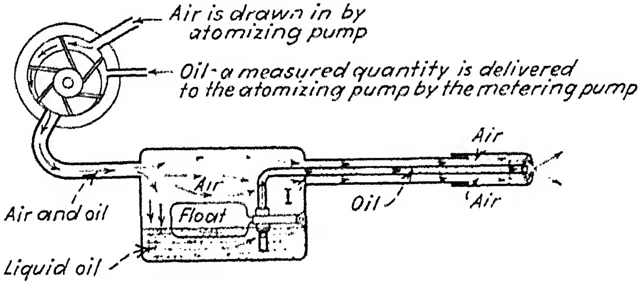


FIG. 58.—Movable-blade type of blower as applied to pressure-atomizing burner.

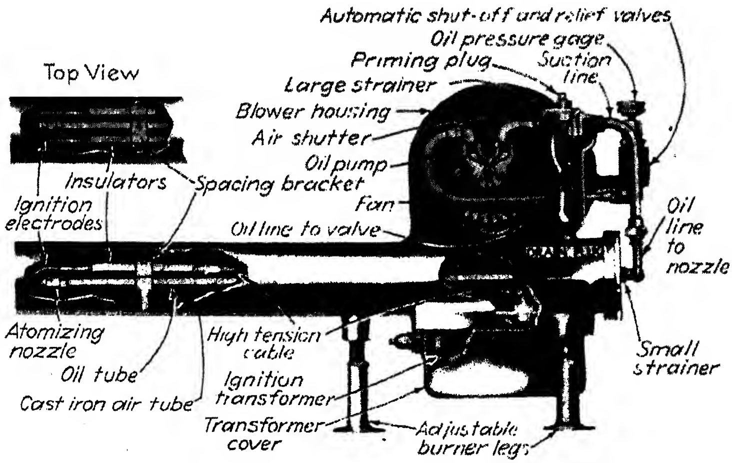


FIG. 59.—Horizontal pressure-operated oil burner with short-blade (Sirocco type) centrifugal fan.

strainers (page 126), ignition device, and atomizing nozzle are plainly marked. Details of a similar oil burner are shown in Fig. 53 (page 88).

Figure 60 shows the method of support of the vertical shaft of the atomizer of an oil burner. The armature of the electric motor is marked A, the shaft S, and the ball-type thrust bearing B.

Hearth Flames and Wall-wiping Flames.—Depending more especially on the adjustment rather than on the design, *rotary types* of atomizing burners may produce either of two types of flame or a combination of these two types. The two types referred to are (1) the hearth flame and (2) the wall-wiping flame.

Hearth flame as used in connection with a vertical-shaft rotary burner, is the flame in an oil-atomizing burner in which combustion begins practically as soon as the combustible mixture of oil and air leaves the rotating parts of the burner, meaning usually the metal cup at the top of the vertical shaft. Combustion of this kind usually results in a flat circular sheet of flame which spreads itself over the entire area of the hearth.*

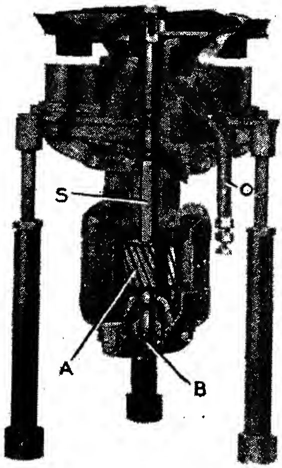


FIG. 60.—Typical shaft of vertical burner showing thrust bearing at bottom.

The wall-wiping flame in a vertical-shaft atomizing oil burner is the kind of combustion that takes place almost entirely at the side wall of the refractory material around the circumference of the hearth; this means, of course, that there is practically no combustion at or near the central portion of the firepot. Such a wall-wiping flame must not be allowed to touch the metal heating surfaces that constitute the water legs (page 89) of a steam or a hot-water boiler. If the wall-wiping flame makes such contact with these cooled metal surfaces, the combustible mixture of oil and air will be cooled below the temperature at which complete combustion occurs; consequently there will be unsatisfactory burning of the oil fuel, so that much of it will be burned to carbon monoxide (CO) (page 26) instead of carbon dioxide (CO_2). On the other hand, if in such an oil burner the arrangement of parts is changed so that the contact of the flame is only with the very hot ring of the refractory material set up on the hearth-sup-

* In some vertical-shaft oil burners, instead of the flat circular flame, there is formed a ball-like mass of flame in the central part of the firepot.

port plate *H* (Fig. 54), combustion will be improved. The combustion ring for most of the types of wall-wiping flame burners is made of specially designed bricks furnished by the burner manufacturer.

Comparison of Rotary-ring or Rotary-cup and Pressure or Gun Types.—In some cases the selection of an oil burner will be made on the basis of the kind of firepot in which the oil burner is to be placed. It is probably obvious that a vertical-shaft rotary atomizing burner is almost ideally suited to operation in a heater with a circular firepot. In that case the oil burner can be placed in a central position and practically the same flame lengths will be thrown out in all directions. In heaters with oblong firepots, if the rotary type is installed, some parts of the firepot walls will receive more of the combustible mixture and considerably more heat than others. On the other hand, if such a burner is to be installed in a firepot in which the length is not much greater than the width, the inequality of dimensions will not be of serious importance. However, if the length greatly exceeds the width, especially if it is nearly twice the width, the rotary type cannot be used with prospects of reasonable success. Again, the flame from a *pressure-atomizing* oil burner can be varied in shape from a long and narrow one to one that is relatively short and wide. A certain minimum length is necessary, however, for any given capacity since the high velocity of the atomized oil makes flame impingement undesirable because of the possibility of erosion effects (page 59).

Satisfactory location of a *pressure-atomizing* oil burner in some cases may therefore be somewhat difficult in a nearly circular or a nearly square firepot. This type of oil burner is especially suited, however, to firepots that are long and narrow; for this service, obviously, they are almost ideally suited. Nevertheless, experts in the servicing of many types of automatic oil burners state that in the vast majority of cases either the rotary-atomizing or the pressure-atomizing types will give satisfaction if the installation is carefully worked out. In any case, however, good materials and workmanship in the burner itself and proper installation are of great importance.

Typical Design Combinations.—It is frequently stated that nearly all oil burners are actually operated by a combination of both atomization and vaporization. However, most cases in

practice do not so clearly separate the atomizing from the vaporizing function, as in Fig. 61. In this case, the *atomization* is performed in the right-hand part of the device, and *vaporization* takes place in a separate chamber or *retort* at the left-hand side. The essential features of the atomizing equipment of the burner are: (1) The constant-level float chamber; (2) the atomizing oil-fuel orifice; (3) the motor-operated centrifugal fan which is directly connected to the electric motor. A drain pipe *D* extends downward from the float chamber to a safety bucket which receives also the overflow from the burner through the pipe *P*. In the operation of this safety bucket, when leakage oil fuel accumulates in considerable amount, the weight of the oil in the bucket trips a valve which shuts off any further supply

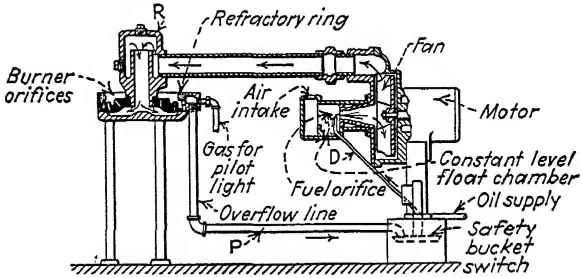


FIG. 61.—Oil burner with retort for vaporization.

of oil to the burner. In this case, the fan performs two distinct services: Firstly, it creates a suction which draws the liquid oil fuel from the float chamber through the atomizing nozzle; and secondly, it mixes the atomized oil fuel with the air entering at the air intake above the orifice. The discharge from the fan passes in the direction shown by the arrows to the vaporizing retort *R*, which is kept heated to a high temperature in the normal operation of the burner; and, because of the high temperature in the retort, it actually becomes a "cracking" chamber where the atomized oil fuel in the mixture of oil and air is vaporized and the contained air in the mixture is at the same time preheated. The combustible mixture thus obtained is discharged through the burner orifices which are clearly marked in the figure. Gas for supplying a pilot light is conducted to the burner orifices by the pipe shown in the right-hand side of the retort. This gas pilot light serves for starting the combustion at the burner orifices,

but when the refractory ring surrounding the burner becomes sufficiently heated, combustion is continued automatically. The gaseous combustible resulting from the combination of

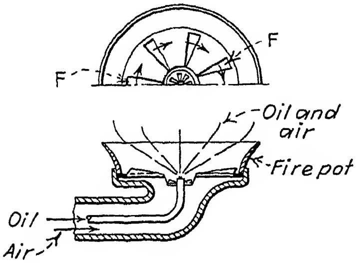


FIG. 62.—Pressure type of oil burner with centrifugal fan blades for mixing and flattening the flame.

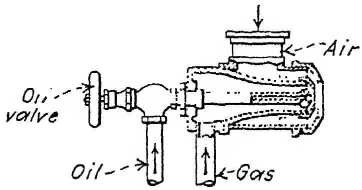


FIG. 63.—Combination burner for oil and gas.

atomization and vaporization burns with a characteristic blue flame at the burner ring.

An interesting device which is applied for the purpose of producing a sharply flattened flame in the burner is shown in Fig. 62. It illustrates a pressure-atomizer head with a vertical

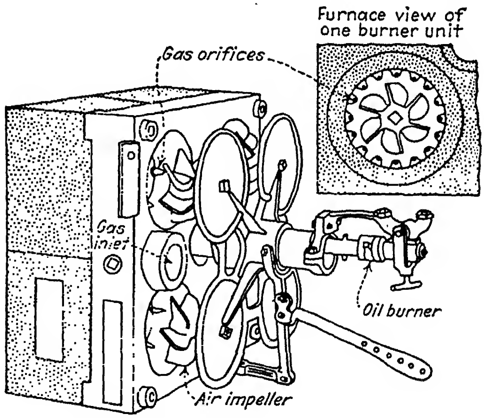


FIG. 64.—Combination multiple burner for oil and gas.

shaft provided with mechanical draft from a suitably located centrifugal fan for the purpose of whirling and rotating the air as it mixes with the atomized oil fuel. The fan blades in the figure are marked *F*, *F*. There must obviously be a slight amount of

clearance between the fan blades and the bottom of the firepot (not shown in the figure).

Figure 63 shows the details of a combination oil and gas burner. A somewhat different multiple burner for the same kind of service is illustrated in Fig. 64.

Combination oil and gas burners are not only used for either gas or oil separately, but are sometimes used also with the two kinds of fuels burning at the same time. The practical necessity of mixing thoroughly natural gas with the air for combustion makes this combination of fuels very desirable for the reason that the discharge of the atomized oil at relatively high velocity into the mixture of natural gas and air produces, as a rule, a much better combustible mixture than is obtained when the combustion mixture in the oil burner consists only of natural gas and air.

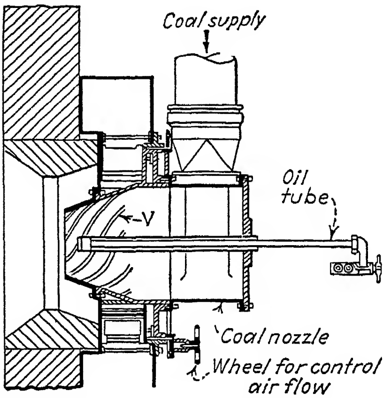


FIG. 65.—Combination burner for oil and pulverized coal.

A combination burner intended for operation with a mixed "feed" of oil and pulverized coal is shown in Fig. 65. Turbulent mixing is obtained by the action on the coal stream of the secondary air supply that enters through the adjustable vanes V.

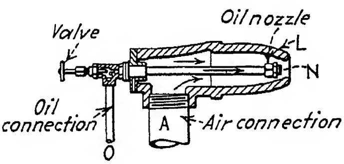


FIG. 6.—Industrial oil burner with pressure-type nozzle.

A type of oil burner intended for pressure atomization of oil with low-pressure air supply and especially suitable for industrial uses, such as heat-treating plants, is shown in Fig. 66. This burner is equipped with a suitable oil nozzle, and the air required for atomization is supplied by a blower (page 67) at gage pressures that may be as high as 2 or 3 pounds per square inch. The parts of the atomizer are clearly marked. The control and shut-off valve V, the nozzle tip N, the spray head L, the oil pipe O, and the air pipe A are as illustrated. The directions of flow of oil and air are indicated by arrows.

Combination of Oil Burner and Steam or Hot-water Boiler.—In very few cases is it possible to install an oil burner in a steam or hot-water boiler so successfully that the maximum efficiency for heat transmission to the water in the boiler is obtained. Especially in new installations there is always the uncertainty as to responsibility for operating difficulties when the boiler and the oil burner are made and installed by different agencies. For this reason, some manufacturers of oil burners have also undertaken

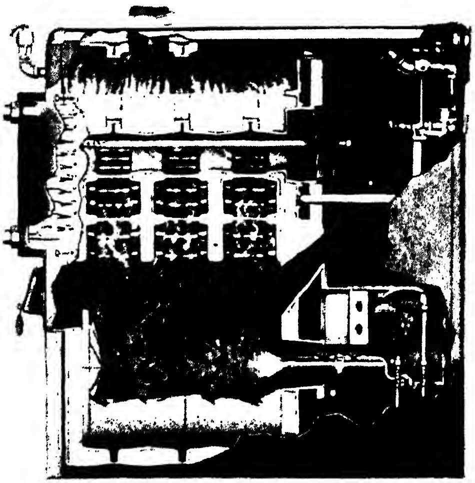


FIG. 67.—Steam boiler with built-in oil burner.

the design and construction of steam and hot-water boilers with the intention of so arranging the heating surfaces of the boiler that the best possible efficiency will be obtained from the combustion of oil fuel in the burner. In such combination units of boiler and oil burner it is possible to attain with considerable success the following advantages: (1) Proper arrangement and a sufficiently large heating surface for the type of oil burner used; (2) dimensions of the combustion chamber to fit the size and shape of the flame produced by the oil burner. Two designs of combinations of boiler and oil burner are shown in Figs. 67 and 68.

Figure 38 (page 73) has been designed with these possibilities in view. It will be observed that there is provided in this

combination heater a coil for heating water for domestic services (page 102).

Steam and Hot-water Boilers.—Until recent years cast-iron boilers were used almost exclusively for the heating of residences and relatively small buildings. The type of cast-iron boilers best suited to operation with a rotary oil-burning flame is the *round type* shown in Fig. 69. A round, cast-iron boiler of a given

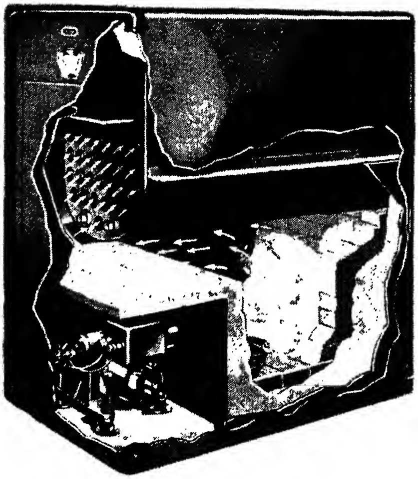


FIG. 68.—Hot-water boiler with built-in oil burner.

diameter can be varied in the amount of heating surface by the simple expedient of increasing or decreasing the number of castings that are included between the top section T of the boiler and the central section C. In other words, the variable heating surface in this boiler is between the top section and the central section which are held together by the vertical bolts B, as shown at the side of the boiler. The general rule may be stated that the efficiency of a cast-iron boiler of this type will be increased within practical limits, with every addition of a sectional unit of heating surface between the top section T and the central section C.*

* Increasing the heating surface in a boiler by the addition of sections of heating surface without changing the area of a firepot obviously increases the ratio of heating surface to firepot area which, in practical effect, is similar

A commonly used cast-iron boiler is the *rectangular-firepot* type shown in Fig. 70. This sectional boiler is intended for burning solid fuel; but it is fairly well adapted to the operation with a torch type of oil burner in which the combustible mixture of oil fuel and air may be discharged through the front opening, marked *A* in the figure. A sectional boiler of this kind consists usually of cast-iron sections, as lettered consecutively in the figure *A*, *B*, *C*, *D*, *E*, *F*, and *G*. In other words, the boiler

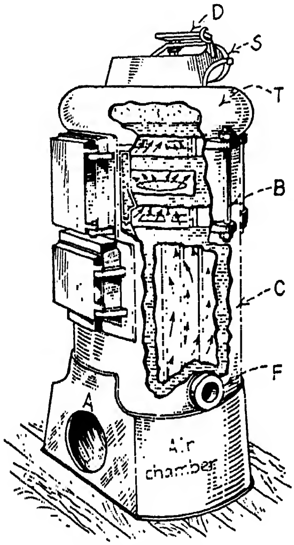


FIG. 69.—Round-sectional steam boiler.

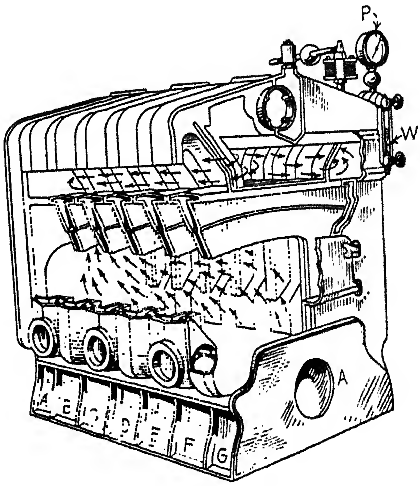


FIG. 70.—Rectangular-sectional steam boiler.

as shown would consist of seven sections; and in practice, boilers of this type are usually sold with from five to ten sections, the several sections being held together with tight-fitting nipples and bolts. A decided advantage of the sectional type of boiler is that it can be conveniently loaded, unloaded, and carried into buildings in case of replacement, through the average size of doors.

Steel-jacketed Boilers.—A domestic type of steam boiler, much improved in appearance over the ordinary sectional boiler,

in effect to increasing the ratio of the heating surface to the grate area in a coal-burning boiler.

is shown in Fig. 71. Before the present general use of such steel-jacketed boilers, the outer surface of both circular- and rectangular-sectional boilers was usually covered with ordinary insulating cement, the cement covering being used to reduce the heat loss from the boiler. This type of covering was adequate for boilers using solid fuels from which ashes had to be removed, with the consequent distribution of dust on all nearby objects. With the introduction of the relatively clean oil burners, the sectional boiler could, of course, be placed in a compartment that could be made relatively free from dust. It was possible, therefore, to use a room containing an oil-burning boiler or warm-air heater in ways that were not easily possible with boilers and warm-air heaters fired with solid fuel. These other uses that came about for the room con-

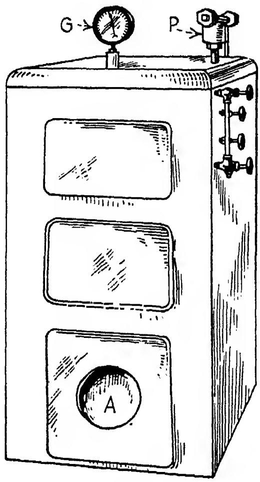


FIG. 71.—Steel-jacketed boiler.

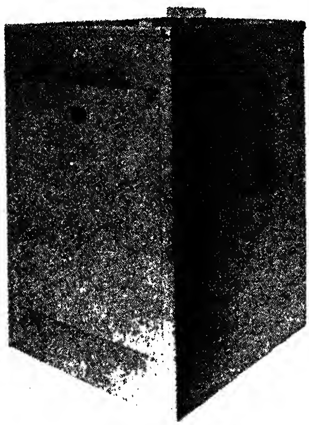


FIG. 72.—Flat-front oil-burning boiler.

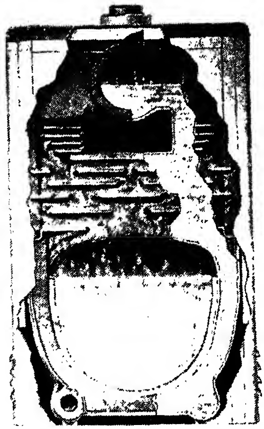


FIG. 73.—Baffles in Delco boiler.

taining the oil-burning equipment created a demand for a boiler covering that is more pleasing in appearance than the ordinary

white cement covering made of heat-insulating material. In order to meet this demand for an attractive boiler covering, steel-jacketed boilers are now being made and widely used.* Another design is shown in Fig. 72.

Baffles in Oil-burning Boilers.—The arrangement of baffle plates that are cast integral with the heating surfaces of the boiler

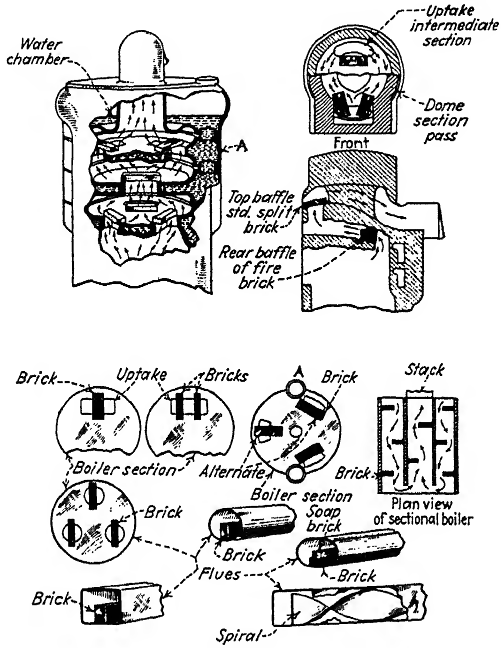


FIG. 74.—Methods of inserting baffles.

is shown in Fig. 73. Methods of inserting baffles as plates or firebricks in "converted" boilers are illustrated in Fig. 74.

The application of a coil for heating hot water for domestic services is shown in Fig. 75. The placement of the hot-water coil over the combustion chamber is an interesting design.

Oil-burner Classification According to Application.—In general, the following services include all those for which oil burners are commonly used:

* The capacities and operating conditions of cast-iron heating boilers are regulated in most states by the Cast-iron Boiler Code of the American Society of Mechanical Engineers. Copies of these regulations may be obtained from the Society at 29 West 39th Street, New York, N. Y.

1. *Domestic burners* for use in the so-called "domestic" heating systems, including those for kitchen ranges. These burners that are intended for small-house heating are usually full automatic, although some are semiautomatic and still others are intended to be controlled by hand (manually).

2. *Commercial burners* for application to heating boilers used for warming stores, office buildings, hotels, schools, large apartment houses, and manufacturing buildings. For this service,

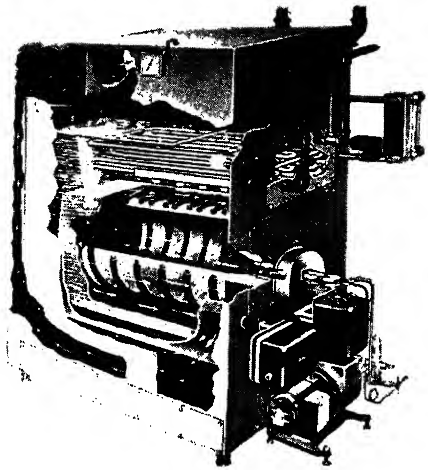


Fig. 75.—Oil-burning boiler with hot-water coil.

the burner may be controlled automatically, semiautomatically, or manually; but most of them are semiautomatic in operation. As a rule, these burners use a heavier grade of fuel oil than is preferably used in domestic burners, and a responsible attendant is in charge of the heating services in the building.

3. *Industrial burners* include those used in boilers of relatively large size for generating steam to be used for power purposes or for merely heating water for industrial processes.

The various successfully used oil burners for these three services vary considerably, even as to design principles, and many are sufficiently flexible to make them applicable for more than one of the above classes of installation.

Oil-injection-type Atomizers and Air Registers.—The type of oil-fuel burner most commonly used in *industrial plants* and in *marine services* has the oil fuel discharged through a suitable pump under pressure, and is provided with *registers* through which the air for combustion passes. Typical air registers are shown in Figs. 78*a* to 78*g*. *Guide vanes* in these registers are used to give uniform distribution of the *air* around the burner. These guide vanes are adjustable and are set to give a flame shape best suited to the shape and size of the furnace. These so-called "mechanical- (pressure-) type burners" have also *diffuser* plates of various shapes which are placed just behind the tip and serve to control the flame shape; they also control any flow of air that might blow out the flame before satisfactory ignition conditions are established. Diffuser plates are adjustable in position axially and are usually set so that the flame fills the burner throat; thus they direct all air coming in through the register to pass through the flame.

In the case of such mechanical burners, the amount of heat developed can be regulated to some extent by changing the oil pressure at the pump; but the range of operation that may be obtained by changing the oil pressure is only about 50 per cent;* and such pressure reduction as is readily possible in a mechanical burner makes the atomization that is obtained at low pressures much coarser than it should be for satisfactory combustion.

Mechanical (pressure) burners are obtainable in large capacity ranges, for example, from 15 to 1,000 gallons of oil per hour. Forced draft (page 346) is usually necessary for high-capacity burners of this type because the resistance to air flow through the register is too large for satisfactory operation with natural draft.†

* The rate of oil flow through a burner varies as the *square root* of the ratio of the pressures so that a gage-pressure reduction from 200 pounds per square inch to 50 pounds only reduces the oil flow through the burner 50 per cent.

† In cases where a number of burners are installed for the same boiler, flexibility of operation may be obtained by cutting out burners. Careful procedure is necessary when one or more nozzles in a group are cut out, to avoid having oil from the operating burners carbonize on the nozzle tips of the burners not operating. In many such cases it is desirable to leave the register of the "cut-out" burners open slightly so that some air can pass through it to prevent overheating the parts of the register; but registers of nonoperating burners should not be wide open as the excess air entering through them will reduce the efficiency of combustion.

Figure 76 shows an *inside-mixing* steam atomizer that gives a flat flame. In its operation steam flowing through *D* cuts across the oil stream, mixes with it, and atomizes the oil as the steam expands through the rectangular orifice. An *outside-mixing* steam-operated industrial atomizer is shown in Fig. 77*a*. Steam

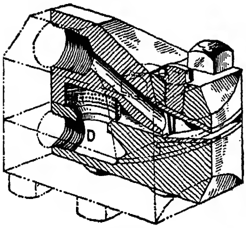


FIG. 76.—Inside-mixing atomizing nozzle.

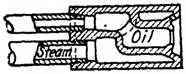


FIG. 77*a*.—Outside-mixing atomizing nozzle.

atomizers in combination with air registers require for satisfactory operation relatively dry steam at, in most types, not much less than 30 pounds per square inch gage pressure, although some are actually operated with apparently good results with steam pressures as low as 10 pounds per square inch.*

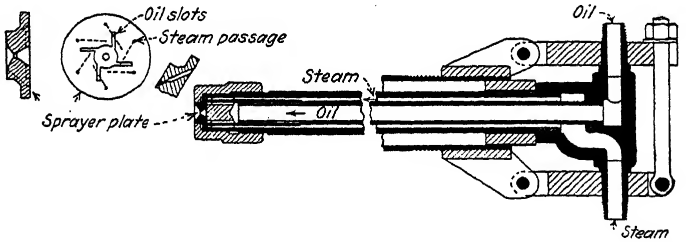


FIG. 77*b*.—Combination pump-operated and steam-operated atomizer.

Steam-atomizing burners are not made for as large capacities as the mechanical (pressure) types. The operating capacity of a steam atomizer is from 20 to 240 gallons per hour.†

Air registers such as that shown in Fig. 78*a* are usually provided for conical-flame pressure-type atomizers, but in the case of flat-

* The lower pressure permissible with steam-operated atomizers makes it possible to design mechanical-type atomizers to operate with oil pressure only for large-capacity service and with steam at low capacity, thus obtaining greater capacity range than is obtainable with the ordinary mechanical type. Figure 77*b* shows an atomizer that is intended for mechanical-type operation at all but small capacities but has provision for steam operation for small-capacity service.

† *Power*, September, 1936, p. 486.

flame steam-atomizing burners, the air for combustion is usually taken in through openings in the floor of the combustion chamber, the openings being made as nearly as possible below the path of

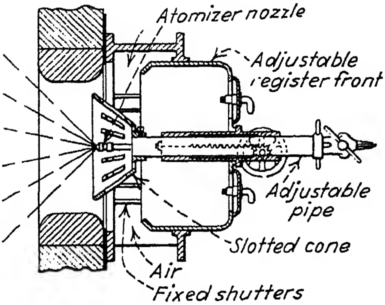


FIG. 78a.—Typical air register with fixed shutters.

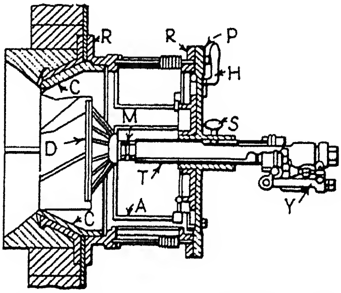


FIG. 78b.—Typical air register with adjustable shutters.

the flame of the burner. In that case, air entering through the furnace-floor openings rises vertically so as to cut across the atomized oil and thoroughly mixes with it. Figures 39 and 40 show floor openings for a different type of burner.

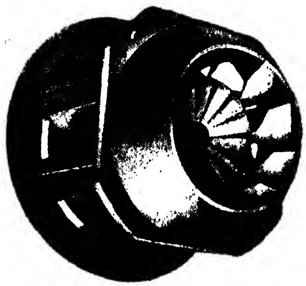


FIG. 78c.—Pictorial view of combustion end of air register shown in Fig. 78b.

Air Registers for Marine and Industrial Burners.—In marine and industrial work, the oil atomizers are usually provided with *air registers*, for the reason that most of the face area of the burner is required for the admission and circulation of the air supply for combustion. These air registers may be used with an air supply without pressure or with a pressure of a few ounces per square inch. Directional vanes may be provided, as shown in Fig. 78a, to control the shape of the flame in the combustion chamber. Shutters are also provided, as shown, which may be either fixed, as in Fig. 78a, or adjustable, as in Figs. 78e and 78f.

One type of oil burner with air register is shown in detail in Fig. 78b. The important parts consist of a cast-iron cone-shaped casing C; a main air register R, which is bolted to the front of the

boiler; automatically operated air doors or shutters A; a front cover plate P, through which a handle H passes which may be used to control the operation of the automatic air doors or shutters A. These doors are all closed by moving this handle in

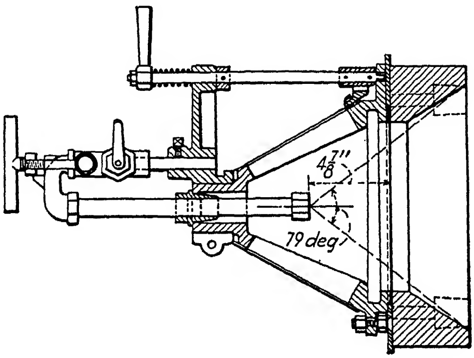


FIG. 78*d*.—Details of forced-draft air register.

one direction, and opened by moving it in the other direction. As a rule, the movement of this handle should be gradual.

The mechanical atomizer itself consists of a hollow tube T, which has attached to it at the fireroom end a yoke Y and at the other end a cone-shaped diffuser D, which is a device for regu-

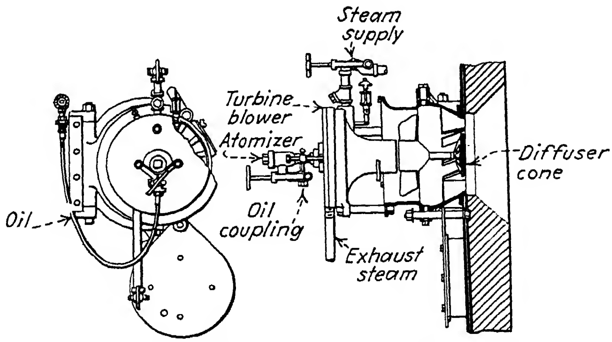


FIG. 78*e*.—Front and side views of typical marine oil burner.

lating the amount of air supplied to the burner. By moving the diffuser in or out through the blades of the cone-shaped casing C, the clear area for the passage of air is decreased or increased. Thus, by pushing the diffuser farther into the cone C, that is,

toward the furnace, the clear area for the passage of air is reduced, and by pulling it out, the area is increased. A setscrew S is provided to hold the diffuser firmly in place with respect to the blades in the cone C and the atomizer tip M. The fuel-oil-supply line is connected to the yoke Y. Another view of this atomizer and air register is shown in Fig. 78c.

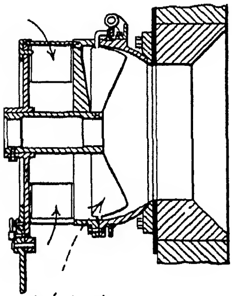


FIG. 78f.—Simple air register with movable air shutters.

A typical forced-draft air-control register intended especially for marine service is shown in Fig. 78d. The atomizer of the burner is shown in this figure as properly located by an exhaustive series of tests made at the U. S. Navy fuel-oil testing plant. Allowance is made for slight adjustment both in and out from the "zero" position. Too great importance cannot be given to the correct location of the atomizer. The forced-draft register is well adapted for destroyers and similar high-power light-weight installations, where the primary object—ability to obtain the maximum power with a minimum of weight—far overshadows all other requisites.

The location of the tip of the burner should be adjusted for every variation of the viscosity of the oil that is burned; also for

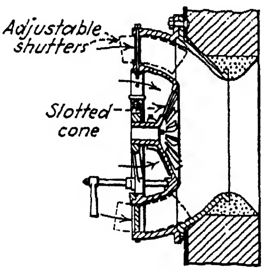


FIG. 78g.—Air register with directed nozzle discharge and adjustable air shutters.

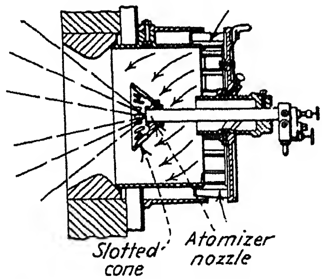


FIG. 78h.—Air register with stationary air shutters.

every change in the oil pressure, and for every considerable change in the air pressure. A plain mark should be made on every atomizer in order that it may be quickly placed in the zero position, with respect to the air register.

Figure 78e shows the atomizer and attached air register, which is suitable for operation with *natural draft* and at low power. It is so elastic in operation that it is adaptable also for very high capacity under forced draft.

When lighting up a cold boiler, equipped with an industrial type of burner, the diffuser and its cone-shaped casing will be cold, so that any oil from the burner tip which strikes them will collect inside the air registers and run down the boiler front. In order to prevent this condition, the diffuser should be pushed in far enough so that the atomized-oil spray clears the blades of the cone. It will be found that as the furnace and the blades of the cone warm up, the diffuser may be gradually pulled out from the furnace, and then any small amount of fuel oil that strikes

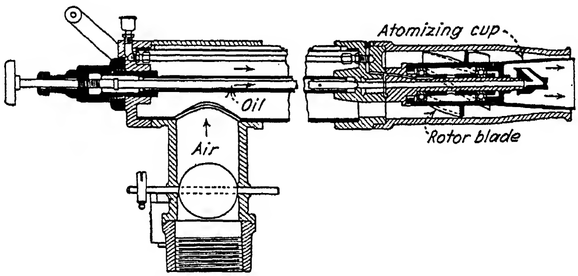


FIG. 79.—Cup-type nozzle with impeller vanes for compressed-air drive.

the blades of the cone will be burned off. After the cone is thoroughly heated, the diffuser should be withdrawn to its best operating position.

Rotary-cup Type of Industrial Burner.—In the rotary-cup type of burner for industrial use the oil is atomized as it is thrown off the rim of a rotating cup. The principle of operation is exactly the same as for the domestic burners that operate with a rotating ring or rotating cup (pages 65–94). The cup may be rotated by air that is directed through *impeller vanes*, as shown in Fig. 79, or the cup may be driven by an electric motor. In still another type the oil fuel is atomized when it is discharged against the vanes of an air-driven *spinner*, as shown in Fig. 80.

This rotary-cup type of burner, when used for industrial services, is usually intended for off-and-on operation. Capacity in comparison with burners provided with air registers is relatively low—not over 100 to 150 gallons of oil per hour.

Oil Burners for Industrial Furnaces.—There are many applications of oil burners for the heating of industrial furnaces. An industrial type of oil burner shown in Fig. 66 (page 97) is used a great deal in furnaces intended for the heat treatment of metals. This burner operates in essential principles as a pressure-type atomizer, which has air supplied at the air connection of the burner under pressure. The air is supplied by a blower which, in some cases, will be discharged at a gage pressure as high as 1 or 2 pounds per square inch. The supply of oil for the burner is regulated by the control valve *V* at the left-hand side. The oil pressure gives considerable velocity to the discharge of the atomized oil fuel from the spray head *L*. The combustible mixture of atomized fuel oil and combustion air is discharged from the lips of the nozzle *N*.

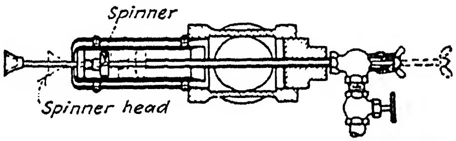


FIG. 80.—Nozzle designed for atomization by air-driven spinner.

Selection of Type of Industrial Oil Burner.—Oil-fuel-injection burners that include an air register are generally selected for large industrial and marine installations because of the large capacities obtainable in a single burner and the somewhat better economy that can be guaranteed.

Steam-operated, flat-flame oil burners are generally preferred for use with horizontal, return-tubular boilers, especially when the steam from the boilers is intended mainly for heating buildings. The reason for this selection is that the flat and more "lazy" flame is likely to be less hazardous from overheating the boiler shell than the liquid-injection (mechanical) type with an air register. Of these two types the steam-atomizing burner is also much cheaper in *first cost,* although the *operating cost* is greater because of the steam supply needed. Rotary-cup burners are especially adaptable for use with fairly large heating boilers, especially when used for off-and-on operation.

Air Tube and Placement of Atomizing Nozzle.—A cylindrical pipe is commonly attached to the discharge of a blower or centrifugal fan delivering all or part of the air required by an oil

burner for supporting combustion. This pipe is usually called the *air tube* and its place of entrance into the firepot of the heater or boiler should be so selected that the oil nozzle will be at, or slightly below and near, the delivery end of this air tube. The object of this arrangement is to "blanket" the oil spray with a continuous flow of air; this flow of blanketing air is intended to obtain close contact of the atomized oil particles with the flow of air.

Guide vanes are usually provided in the discharge end of the air tube with the object of giving a whirling motion to the air so that it will not leave the discharge end of the air tube in too large particles for efficient combustion. However, in spite of the whirling motion thus given to the air by passing through the guide vanes, there is still a *tendency* for the air to move in a straight line (page 50) from the discharge end in very much the same way that the oil fuel discharges from the nozzle. In the best designs of this type of oil burner, the stream of oil particles and the stream of air are made to rotate in opposite directions so that the air stream will meet the particles of oil fuel at nearly right angles with the result that eddying currents will be produced that will thoroughly mix oil-fuel particles with air.

Turbulence.—Not all oil burners are designed to obtain the effect of turbulence when the air discharge is axially in line with the air discharge of the oil nozzle. One variation is the case where the discharge of a blower or relatively high-pressure type of centrifugal fan enters the air tube tangentially. Because of the sudden change of direction of the air discharge, eddy currents are set up in the air flow which produce an effect similar to that in an oil nozzle when the direction of flow of atomizing air is at right angles to the flow of atomized oil fuel (page 70). In such cases guide vanes in the discharge end of the air tube are not needed.

The air tube of some oil burners differs considerably from the conventional types that have been described. The air tube of one oil burner, for example, that is well suited for turbulence is shaped somewhat like a fish-tail gas burner of the kind that was in general urban use for house lighting before the present application of electricity for lighting. This kind of air tube is made so that it is tapered down from a circular cross section to a rectangular section; the latter section has a narrow horizontal slot

in which there is a partition that runs lengthwise so as to form two slots instead of one—a top one and a bottom one. When the air is discharged through these top and bottom slots, two flat horizontal streams of air are produced, one moving slightly upward and the other slightly downward. These upward and downward air streams meet the oil spray a short distance from the nozzle so as to make a flattened, turbulent, and horizontally spreading flame.

In the foregoing discussion of air tubes, it has been made plain that for satisfactory operation of an oil burner, the discharged air must have sufficient eddies and whirling movements to produce a considerable amount of turbulence so that there may be a thorough mixing of the air supply with the atomized particles of

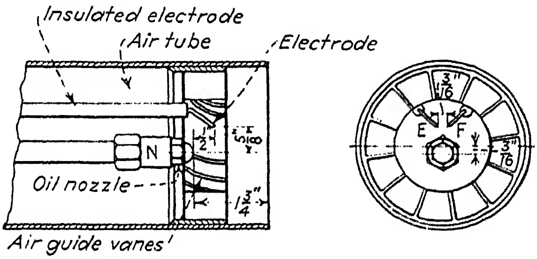


FIG. 81.—Air tube and ignition electrodes of typical pressure-operated oil burner.

oil fuel. The variations in design that have been noted show that there are many ways in which this turbulence may be produced. Just because turbulence is an effective means in the operation of some types of furnaces or boilers that have oil burners for obtaining fairly good combustion, it cannot be assumed that turbulence produced in the same way will successfully bring about complete combustion in some other type of furnace or boiler equipped with the same oil burner, especially if the firepot is of an entirely different shape. It is desirable, therefore, in most oil burners of the pressure type to make some provision for adjustment of the position of the oil nozzle with respect to its placement in the firepot and the shape of the streams of discharged air.

A typical arrangement with dimensions adopted by one manufacturer for the air tube and the air-guide vanes that are placed at the discharge end for turbulent effects is shown in Fig. 81.

Ignition Systems.—There are two general classifications of ignition systems for oil burners. In one kind, the ignition system is in operation continuously, at least during the operation of the oil burner, and in some cases even when the oil burner is not operating. In the other kind, the ignition device operates in full flame only when the burner is started. The former of these two methods of ignition is called "constant ignition" and the latter "cut-off ignition."

Either the constant-ignition or the cut-off-ignition system may be arranged for ignition by means of electric current or of a gas flame. In the electric system, current for the ignition device is supplied at the line voltage (usually 110 to 115 volts) to a transformer not unlike the spark coil in the old-fashioned battery-ignition system used for many years on Ford automobiles. This ignition transformer is used to raise the line voltage high enough to produce a spark across electrodes that are at least 3/16 inch apart. The voltage that is necessary to make a satisfactory spark of this length is about 10,000 volts. In the practical application of this system, the high-voltage current is carried by wires to two electrodes or "sparking points" which are usually located about ½ inch above and about the same distance in front of the discharge tip of the oil nozzle. In some oil burners, the distance between the electrodes is scarcely more than ⅛ inch, while in others the distance is somewhat greater. The distance between electrodes, then, may be said to vary in the various types of oil burners from ⅛ to ¼ inch; but the average or 3/16 inch is the distance between electrodes that is most commonly used.

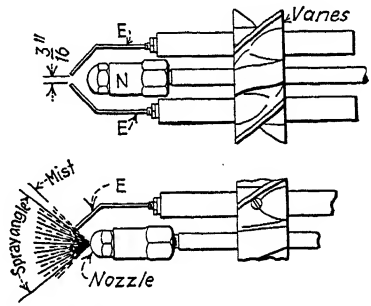


FIG. 82*a*.—Method of electrical ignition with typical oil nozzle.

Figure 81 shows the electrodes *E* and *F* in the end view. Curved air vanes are shown in the front end of the air tube, as is also the oil nozzle in the cross-sectional view. The dimensions shown in this figure are not to be regarded by any means as standard for any or all types of oil burners. They happen to be the dimensions given by one manufacturer and will obviously differ somewhat from other makes using even the same general

type of construction. Dimensions for other designs are shown in Figs. 82*a* and 82*b*. Figure 82*c* shows other details of construction. It is desirable that the electrodes should be a short distance above the oil nozzle, so that some oil vapor will reach

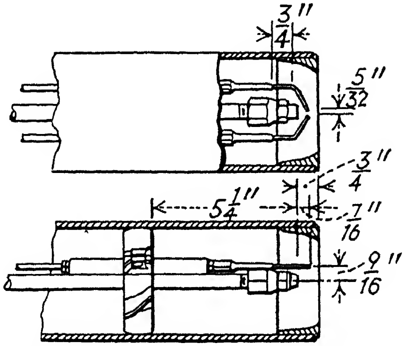


FIG. 82*b*.—Ignition electrodes as located in air tube with vanes to increase turbulence.

the electrodes as soon as possible after the starting of the oil burner.

A *gas-ignition system* uses a small gas pilot light which, in practically all cases, burns continuously whether or not the oil

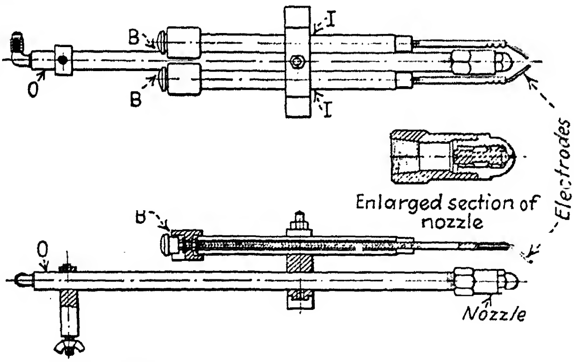


FIG. 82*c*.—Structural details of typical ignition electrodes.

burner is in operation. In some cases, the gas pilot light is reduced to a very low flame after the oil burner begins to operate and some oil vapor has been ignited. In other cases, the gas pilot light burns at its full height continuously, during the "on" and "off" periods of oil-burner operation. When the electric

motor that provides electric power for the oil burner operates also a centrifugal fan, the rush of air from the fan supplying the burner must be regulated so that this air will not extinguish the flame of the gas pilot light before the ignition can be carried on by the hot refractory surfaces. To prevent this occurrence, an "expanding" gas valve may be provided, this valve being usually of the electric *solenoid* type.

Solenoid Valve.—A valve of this kind is shown in Fig. 83, in which the essential part is a vertical cone which is attached to the end of a soft-iron plunger. This plunger (also vertical) is provided to keep the conical valve on its seat when the burner is not operating; in other words, the weight of this plunger holds the cone tightly on its seat when the valve is closed; thus it prevents the flow of gas through the valve. Above the plunger is a *solenoid* which is in essentials a simply wound coil of wire. When current flows through the solenoid, it takes on magnetic properties to such an extent that it is able to raise the plunger and the attached cone so that the valve will be opened. The gas required for the small pilot light flows through a by-pass around the main valve so that it has always a supply of gas. A needle valve which is usually operated by hand is also provided in the by-pass pipe so that the proper size of pilot-light flame may be obtained. In small oil burners, there frequently is a combination of the gas-ignition and the electric-ignition systems. In this combination method an electric spark is used to light a gas burner which may be opened by a solenoid device when the oil burner is started; and then the gas flame ignites the vaporized oil fuel. As a general rule, the gas flame, if kept clean, is a more positive method of ignition than a purely electric device. The gas-electric system has the advantage that there is no need at all to have the gas pilot light burning when the oil burner is not operated. Such a thermostatic safety gas pilot light with a thermal element that operates a mercury switch (page 145) is shown in Fig. 84. The expansion or contraction of the thermal

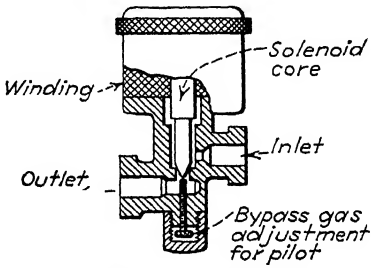
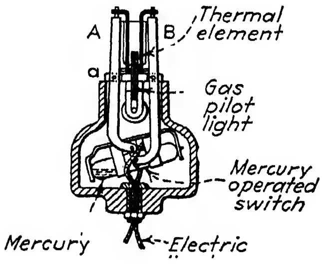


FIG. 83.—Magnetic solenoid valve for gas pilot-light control.

element by heating or cooling moves the switch levers A and B which are pivoted at a and b, respectively.

In order to reduce the cost of operation of the gas pilot light, a so-called "expanding gas pilot light"* has been developed. This improved type of gas pilot light requires only a small amount of gas, except at the moment when the oil burner is being started. During the starting period, the gas pilot light is automatically increased in size to such an extent that its flame ignites the atomized oil fuel which just then is being discharged into the firepot of the burner. In the actual operation of this expanding gas pilot light, the valve controlling the size of the flame is automatically opened wide just a moment before the atomized oil fuel is injected into the firepot of the oil burner. As soon as self-ignition of the atomized oil fuel is established by a sufficiently high temperature, the pilot flame is reduced again to a very small size. Valves controlling the expanding gas pilot light may be operated by a control motor (page 178) or by a magnetic solenoid valve (page 115) with by-pass gas piping as shown in Fig. 83.



G. 84.—Thermostatic safety light with mercury

Slightly different from the expanding gas pilot light just explained is the so-called "gas-electric pilot light." In this there is no small continuously lighted pilot flame; the oil burner is started by the automatic opening of a solenoid type of valve which discharges the gas for a large pilot light, the discharged gas being ignited by a long, hot electric spark obtained from a suitable electric device.

Complete electric ignition is used in many types of automatic oil burners. This type of ignition was developed originally for oil burners in houses where a gas supply was not available and

* In this connection, it should be realized that a gas pilot light is just as efficient in heat generation as any of the burners in a gas-operated heater, and the heat that is developed by a gas pilot light is not all wasted. The only disadvantage of the large pilot light is that the heat produced in this way is considerably more expensive than that produced by the combustion of most of the available oil fuels, to the same extent that gas for a fuel may be more expensive for heat production than oil fuel (page 23). A well-heated firepot is advantageous for obtaining good initial combustion.

therefore a gas pilot light could not be used. Commonly used electric-ignition methods are the following: (1) by a *high-voltage*-spark system; (2) by a *line-voltage* resistance unit; (3) by a *low-voltage* resistance unit; (4) by a *combination* of the high-voltage-spark system with the line-voltage resistance unit. Of the four types listed here, the high-voltage-spark or "arc" system is the one most generally used. The required high voltage for the operation of this system is obtained preferably from a transformer for voltage step-up installed on an electric-power line. The high-voltage spark required for this system, however, may be obtained with less certainty of continuity of service, from the vibrator device of high-voltage-spark coils. The voltage obtainable from a high-voltage vibrator and spark coils is likely to be quite variable so that the quality of the ignition spark will also be variable. On the other hand, the voltage produced by the step-up transformer when operating as is usually the case at 110 volts on alternating current is between 12,000 and 20,000 volts. Obviously this high voltage produces a discharge of long, hot sparks in the gap between the ignition "points" or electrodes, the spark discharge being used to ignite the vaporized oil fuel. The spark gap in an ignition device of this kind is relatively long compared with the gap in the spark plug of an automobile engine (about $\frac{1}{50}$ inch) as it is usually between $\frac{1}{8}$ and $\frac{1}{4}$ inch in length. In some oil burners the high-voltage spark system is intended for operation with a *continuous* discharge of sparks from one electrode to the other. This continuous operation of the sparking device, it is claimed, will give a more reliable ignition than that obtained when the electric spark is made only at the time for the beginning of ignition in the oil burner. It is generally admitted, however, that if the so-called "flame retention" by the refractory surface in the firepot of an oil burner is reliably effective, an *intermittent* type of sparking device is satisfactory. Typical electrodes for a pressure-atomizing burner are shown in Fig. 81. Similar electrodes as suitably located in the air tube of an oil burner are shown in Figs. 82*a*, 82*b*, and 82*c*.

In the system of ignition by a *line-voltage resistance unit* a coil of high-resistance wire is located at the place in the firepot of the oil burner where the ignition of the atomized oil fuel is to occur. In this system the resistance unit is in series with the

electric supply line so that it becomes quickly heated to incandescence and will then ignite the atomized oil fuel. In most places this system of ignition is not considered so satisfactory as it should be, for the reason that the temperature of the coil is likely to vary a good deal with fluctuations of the line voltage of the electric-current supply.

Low-voltage resistance units when used for oil-burner ignition are not affected by voltage fluctuations in the same way as line-voltage resistance units. Voltage fluctuations are avoided by the use of a step-down *constant-current transformer* which reduces the line voltage. With a constant line current in the resistance unit, its temperature can be maintained without any appreciable variation, regardless of fluctuations of line voltage. A constant-current transformer may be used to accomplish this result.

Selection of Ignition System for Domestic Oil Burners.—The first requirement of the ignition system of an automatic domestic oil burner is, of course, reliability. In this connection, it must be kept in mind that in order to ignite the mixture of atomized oil fuel when mixed with the air for combustion, it is necessary to produce a sufficient amount of heat so that some part of the ignition device will be raised to a sufficiently high temperature to produce combustion. The number and location of ignition electrodes and pilot lights must also be considered, and these matters will depend a great deal on the size and shape of the combustion chamber in which the oil burner is located. Actually, the correct setting for the different types of oil burners must usually be determined experimentally by the manufacturer, and for this reason the installation directions in regard to ignition electrodes and pilot lights must be very carefully followed. Chimney draft (page 348) is an important element to be considered in some installations, as it may be a cause of ignition troubles, especially with gas pilot lights. Excessive chimney draft is likely to draw the mixture of oil-fuel vapor and the air for combustion away from a gas pilot light, so that there will be considerably delayed ignition or possibly no ignition at all until suitable changes are made in the chimney draft. On the other hand, it has been found that insufficient draft from the chimney or "back-draft" may put out a gas pilot light. Oil burners of the domestic type that are operated with a continually burning gas pilot light (page 89) should be provided with a thermostati-

cally operated safety switch as a protection against flooding the firepot with oil fuel in case the pilot light should be blown out by chimney draft or in some other way. This thermostatic device operates by the method of holding an electric switch in the line circuit closed as long as there is a normal amount of heat from the pilot flame. If, however, the pilot flame is extinguished in any way, or if the pilot-light burner becomes clogged with foreign matter so that the flame is much smaller than the size required for reliable oil-vapor ignition, the thermostatic safety switch cools off to such an extent that it opens a switch in the electric supply line and thus prevents the further operation of the oil burner. When the operation of the oil burner is stopped by the cooling off of the thermostatic safety switch at the pilot light, it will take a number of minutes after the gas pilot light is again burning at its normal height to heat the thermostatic elements of the switch to such an extent that they will close the electric switch in the supply line to permit the operation of the oil burner.

Trouble Chart of Motors and Generators.*—Almost all unusual happenings on an electric motor indicate that there is some operating trouble. Such happenings may be accompanied by smoke, flame, or pounding, or they may be of apparent minor importance, such as sparking, sudden changes in speed, and frequent blowing of fuses. It is advisable, after any such unusual occurrence, to make a careful investigation and test.

	Cause
Noise	Loose bolts or screws Out of line—vibration Rubbing or improper end play—pounding Brush trouble—squeaking Loose belt—flapping
Brush sparking	Overload or brushes set wrong Rough commutator, or sticky or broken brushes Armature winding damaged
Heating of coil	Overload or poor ventilation Short-circuited or grounded windings Moisture

*Electric motor troubles are explained more in detail in "Industrial Electricity and Wiring," by James A. Moyer and John F. Wostrel, 2d ed., 1936, McGraw-Hill Book Company, Inc., New York.

	Cause
Heating of bearing	Poor alignment or bent shaft or rubbing Bearing too tight, scored, or dirty Poor or insufficient lubrication Belt too tight
Hot commutator	Sparking Poor brush contact Unsatisfactory ventilation
Blowing fuses	Low voltage on mains Overload Short circuit or ground on coils
High motor speed	Field current too small or field open Wrong connections Brushes set wrong Insufficient load on series motor
Low motor speed	Overload or too great friction Open armature connections or leads Brushes set wrong Weak magnetic field
Will not start	Overload Load locked or on dead center Starting device in trouble Open phase Short-circuited resistance of wound-rotor type Excessive friction Short circuit in the field coils or in the armature
Runs backward	Wrong connections

Often the damage to a motor may be insignificant and easily repaired if located, whereas if not corrected, it may develop into a serious failure of the machine. The best rule is to stop and investigate.

Principles of Electricity.—Since most oil-burner controls are operated electrically, a few electrical principles will be explained before the details of control apparatus are discussed.

A complete circuit is necessary for the operation of any electrical device. For example, suppose the device to be used is a motor. An electrical conductor (usually a wire or cable) must be provided from the electric-current supply line up to and through the motor, and back again to the supply line. If this circuit is broken or "opened" at any point, the flow of current is interrupted and the motor stops.

"Hot" Line and Ground Line.—One side of all *power* circuits, that is, one of the wires, is always "grounded" or connected to the earth. That wire is known as the "ground" wire, and the other as the "hot" or "live" wire or line. Any switch designed to open the circuit and stop the motor must be placed in the "hot" wire. Otherwise a ground connection in the apparatus may provide a "return" circuit through the earth, and the switch will be useless.

The *electromotive* force tending to cause a current of electricity to flow through a circuit is measured in *volts* and is usually referred to as the voltage. This may be thought of as roughly similar to the pressure tending to cause the flow of water through a piping system. The standard for supply to buildings is nearly everywhere 110 to 115 volts. The amount of current flowing is measured in *amperes,* which may be compared with the amount of water flowing in gallons per minute.

Alternating and Direct Current.—If the flow of electricity in a circuit is always in the same direction, it is described as "direct current" (abbreviated d.c.). In most cases the current in the supply lines is what is called "alternating current" (abbreviated a.c.), that is, the current flows in *cycles,* first in one direction and then in the opposite direction. This is known as one cycle. Practically all alternating current for motor operation is supplied at a *frequency* of 60 cycles per second.

It will be obvious that electrical apparatus must be designed for the voltage and frequency of the current which is to operate them. Such devices usually have a name plate which shows the current characteristics for which they are designed. The local power company should always be consulted regarding the voltage and frequency of the current supplied.

Electromagnetic Relay.—An *electromagnet* consists of a piece of soft iron surrounded by a coil of wire. If a current flows through the coil, the iron becomes magnetized and will attract any nearby iron or steel objects. If the current is stopped, the soft-iron core in the coil loses its magnetism. Such an electromagnet may be arranged to open or close a switch, and when so arranged, the entire device is known as a *"relay."* Relays are used in most modern control systems.

Solenoid.—A coil of wire generally wound on a wooden or other insulating spool, so that the winding is always in the same direc-

tion, layer upon layer, similar to the winding of a spool of thread, is called a "solenoid."

Transformer.—Two coils of wire placed close together, but with no electrical connection between them will react on each other, when there is a current of electricity in one or both of them. One of these may be called the *primary* and the other the *secondary* coil. When the primary coil is connected to a source of electric power so that a steady current flows through it, nothing happens in the secondary coil. If, however, the current in the primary coil changes in any way, it will build up a voltage in the secondary coil *while the change is taking place.* If the primary coil is connected to an alternating-current supply, obviously its current will be continually changing, and a similar alternating current will be set up in the secondary coil. This phenomenon is known as *induction.*

Furthermore, for any given voltage in the primary coil, the voltage in the secondary coil will depend only on the relative number of turns of wire in the two coils. If the primary coil is connected to the usual 110-volt power line, any desired voltage in the secondary circuit may be obtained by properly proportioning the number of turns of wire. Such a device, called a *transformer* is generally used to obtain the supply of low-voltage current for the control circuits of oil burners. A transformer cannot be used if the power supply in its primary coil is direct current, since such a current is *steady* and so will have *no inductive effect* on the secondary coil.

If the secondary-coil circuit is open so that no current can flow through it, the combined induction in the two coils builds up an opposing voltage in the primary coil and "chokes" the flow of current through it. In other words, even though the primary coil is connected to the power lines, no appreciable current can flow through it unless a current can flow through the secondary circuit.

Ohmic and Inductive Resistances.—In a circuit in which there is no measurable *induction,* such as one containing incandescent lamps or electric heaters, all of which are noninductive, the resistance is called *ohmic resistance.* On the other hand, in an inductive circuit as, for example, one that includes arc lamps, solenoids, transformers, and most types of industrial and household motors, the resistance to alternating current is an *inductive resistance.*

Oil-fuel Preheating and Pressures.—The oil fuel which is delivered to the atomizer of an oil burner may be preheated if necessary in order to secure satisfactory operation of the oil pump and the atomizing device.

The oil supply for *industrial* atomizers is usually at a gage pressure of from 50 to 200 pounds per square inch; the pressure to be used within this range depends on the grade of oil that is to be burned. The oil fuel is discharged most successfully from the tip of the atomizing device by the combined action of centrifugal force and the rapid expansion that occurs in a vapor when the pressure is suddenly reduced.

Effect of Viscosity on Discharge of Oil Through Nozzles.—The amount of oil that will be discharged from an oil nozzle will depend on the pressure of the oil supply, and it will also depend on the viscosity (page 198) of the oil. When, therefore, the grade of oil used in an oil burner is changed so that the viscosity is higher or lower than that of the oil that was used before, it may be expected that there will be a change in the amount of oil being delivered by the nozzle.* This change in rate of discharge is, in that case, due to viscosity; the viscosity increases, of course, with the lowering of the temperature of the fuel oil. It is not unusual, therefore, when the heavier grades of fuel oil are used in oil burners, that the viscosity will change the heat capacity of the oil burner so much that a readjustment of the oil pressure or of the air supply or both may be necessary.

Oil Heaters.—The heavier grades of oil fuel that are used in *industrial and marine types* of oil burners make it necessary to provide in most of these installations a means for heating the oil in order to obtain satisfactory atomization in the burner and also the proper flow of the oil fuel through the piping and the pump. The heater that is used to promote an easy flow of the oil fuel from the storage tank is called the *suction* or *tank* heater.

Suction or Tank Heaters.—Such heaters are used only when the temperature of the oil fuel in the supply tank is so low that the oil cannot be pumped satisfactorily. They should be large enough to heat the oil in the suction line of the pump to a temperature of from 70° to 95°F., the lower temperature applying, of course, to

* Nozzles are rated by manufacturers of oil-burning equipment usually in gallons per hour at 100 pounds per square inch gage pressure and about 100 "seconds" viscosity (p. 200).

the lighter grades of fuel oil. Suction or tank heaters are supplied with heat in many large installations by steam. This steam for heating, whatever its source, may be circulated in the heater by various means. In a case where there is a long suction pipe between the oil-fuel tank and the oil pump, a double-pipe or manifold type of oil heater may be needed in order to obtain a steady flow into the suction of the pump. A heater of this kind is shown in Fig. 85*a*. In this heater the steam enters at the right-hand end and its condensation is removed from the opposite end. The direction of oil flow, on the other hand, is from left to right, so that the counterflow principle is applied; that is, the

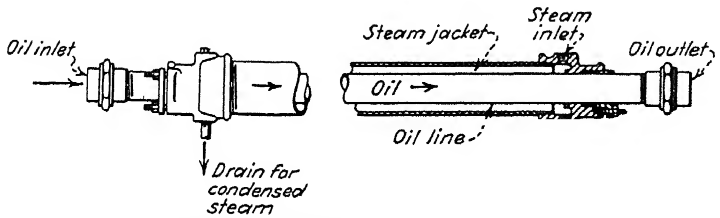


FIG. 85*a*.—Manifold type of oil heater.

steam flows in the opposite direction to the flow of the oil. For the lighter grades of fuel oil, hot water is sometimes used in the suction or tank heater for heating the oil.

Discharge Heaters.—In order to provide a means for the efficient atomization of the *heavy types of oil fuels*, suitably designed heaters are provided to reduce the viscosity of the oil. Such heaters should be located as close to the burner as structural conditions will permit in order to obtain the best possible burner operation and to avoid excessive heat losses from the heaters. Because these heaters are necessarily on the discharge side of the oil pump, they are called *discharge heaters*. In oil-burner installations intended for No. 5 or No. 6 fuel oil (page 17), discharge heaters should be provided, and in the case of industrial types of pressure-atomizing burners (page 103) they may be used advantageously for No. 4 fuel oil.*

* There are many industrial oil-burning installations which use fuel oil as viscous as No. 5 grade, yet are not provided with any preheating equipment (neither discharge nor tank heaters); but this is not a good practice. Most of the time, carefully selected No. 5 grade fuel oil can probably be burned successfully with such modified equipment, but there is no certainty

At least two discharge heaters should always be installed, each having a sufficient capacity for the maximum heating load of the burner installation. This arrangement permits cleaning and inspection without interruption of service. In places where repair parts are not easily available as on shipboard an extra discharge heater may well be carried as a reserve.

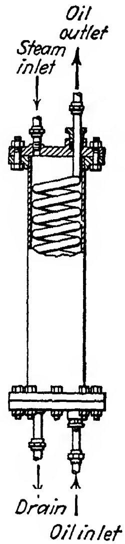


FIG. 85b.—Coil type of oil heater.

Single-coil discharge heaters are commonly used for small installations. A typical example is shown in Fig. 85b. Such heaters are cheap in first cost and are easily cleaned. Multiple-coil heaters of similar construction are more efficient than the single-coil type and are intended for large oil-burner installations. A type of discharge-oil heater used in many oil-burner installations is shown in Fig. 85c. This heater consists of a cylindrical tank containing a double-tube arrangement of corrugated pipes *A* and *B*, of nearly the same diameter; the pipe *A* is inside the pipe *B*, with only enough space between them for a *film* of liquid to pass through. The corrugations are spirally arranged to give increased agitation to the film of oil in its passage through the heater. The steam used for heating enters at the top and divides, part of it passing through the inside *heating* surface of the tube *A*, and the other part passing around the outside surface of the tube *B*. Both of these flows of steam discharge through the outlet. The oil to be heated enters at *E*, and passing through the narrow space between the corrugated pipes *A* and *B* leaves at *F*. Provision is made so that if the person in charge of the heater should happen to close the inlet and the outlet oil valves without shutting off the steam supply to the heater, a safety valve will open and relieve the pressure which

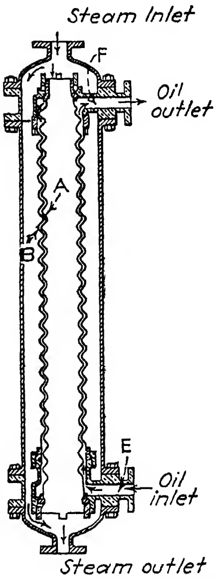


FIG. 85c.—Film type of oil heater.

that now and then a shipment of No. 5 oil will not make trouble. At least a discharge heater should be installed in such cases.

would result from excessive heating of the noncirculating oil in the corrugated, spiral pipes. Film-type heaters are very efficient, and are suitable for large capacities.

Oil-fuel Strainers.—For the satisfactory operation of all types of oil burners, suitable strainers are needed. Domestic types of burners require only a very simple arrangement of a piece of metal gauze, usually in a cylindrical shape placed in a suitable casing threaded for insertion in the oil-supply line. The number of meshes per inch in the strainer gauze depends on the grade of the oil used. Obviously the mesh of the gauze should not be finer than is necessary for the protection of the oil-supply line where the strainer is located.

Strainers on the suction or inlet side of the oil pump, called *suction strainers*, should have from 8 to 20 meshes per inch for Nos. 5 and 6 fuel oil, and from 20 to 30 meshes for Nos. 3 and 4 oil. The strainers on the *discharge* side of the pump may have from 20 to 30 meshes per inch for all grades of heavy oil from No. 3 to No. 6. For the lighter fuel oils (especially Nos. 1 and 2) the suction strainers should have 30 meshes per inch and the discharge strainers 40 meshes. Some domestic types of oil burners are equipped with oil strainers that are similar in construction to those used in the gasoline-feed line of automobiles.*

Strainer trouble in new installations of oil burners may be largely avoided by the careful use of pipe-joint compounds when connecting the pipes to fittings in the oil lines. The correct method of using such compounds is to turn the pipe into the fittings to the extent of one or two threads, then apply the compound to the remaining (exposed) threads. This method will prevent the compound from entering the pipes. It is a good practice to clean carefully the inside surfaces of pipes used for oil lines before they are connected to fittings.

The recommended† size for either suction or discharge screens is 4 square inches per gallon of oil passing through them per hour.‡

* "Gasoline Automobiles," by James A. Moyer, 4th ed., p. 153, McGraw-Hill Book Company, Inc., New York, 1933.

† Recommendation of Underwriters' Laboratories does not state whether the area of screens is net or total. It is considered the best practice to regard this as the effective area; that is, the net area of the screen openings between the wires rather than the total area of the screen.

‡ The effectiveness of a strainer may be determined by attaching a pressure gage by means of a three-way valve to both sides of the strainer.

A straining device used for cleaning very heavy fuel oil before it goes to the burners consists of a pair of "basket" strainers connected into the oil piping side by side (in parallel) with a three-way-cock arrangement so that a quarter turn of the handle of the cock will change the flow of oil from one strainer to the other. In this way the basket of the strainer which has previously been filling may be entirely out of service to be removed and cleaned. The flow of oil from one strainer to the other can be changed so quickly that there will be no appreciable interruption of the flow of oil to the burner. This feature is important because any stoppage of the oil-fuel supply to the burners would, of course, extinguish the fire in the boiler. A more elaborately designed fuel-oil strainer is shown in Fig. 86. This strainer has a twin-basket arrangement with provision for the easy removal of either of the baskets *A* or *B* through securely covered openings in the side walls of the casing. The valves *V* and *W* are operated by the hand-wheels *C* and *D* to direct the flow of oil from one basket strainer to the other.

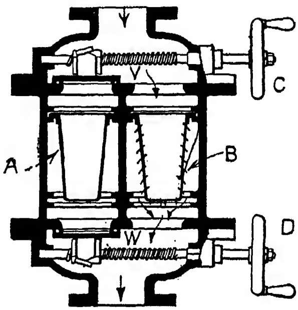


Fig. 86.—Oil-fuel strainer.

Safety Devices for Oil Burners.—When a steam boiler receives its heat from an oil burner, the usual precautions are necessary in order to prevent (1) the generation of steam at a dangerously high pressure; (2) the possibility of damage from a too low water level; and (3) the fire hazard that occurs when the flame in the burner is put out, so that there would be a flooding by oil in the base of the burner and possibly also on the floor of the room containing the boiler and burner.

Pressure Limit Control.—To prevent the development in a steam boiler of an excessive pressure, an electric contact-making safety pressure device is attached directly to the steam space in the boiler. Such a safety pressure device would be connected up to the electric wiring of the oil burner in such a way that if the boiler pressure becomes excessive the electric switch controlled by it will be opened, and the operation of the oil burner will be stopped. (See safety control *G* in Fig. 46, page 79.)

Safety Low-water Cut-out.—A float-operated switch is the type of safety device that is commonly used to avoid the danger of low water. In the operation of this safety device, a switch in the electric circuit supplying electricity for the operation of the motor on the oil burner is opened when the water level in the boiler becomes dangerously low.

The float-operated switch as well as the safety pressure switch are so connected into the electric-supply circuit that either will stop the operation of the oil burner, even when the thermostatic control device for temperature regulation (page 115) is at a temperature requiring the continued supply of heat and consequently the operation of the oil burner.

In the case of a hot-water boiler or a warm-air furnace which is heated with an oil burner, there is practically no danger of the development of dangerously excessive pressure in either of these combustion units or in the heating system. Briefly, a pressure-control electric switch is not needed on a hot-water boiler; furthermore, because the whole heating system connected to the hot-water boiler is filled with water, there can be no danger from low water, at least until the heating system had practically ceased to function because of the lack of water for the heating of any rooms having radiators above the top of the boiler. A *temperature* limit control is however needed with warm-air heaters or hot-water boilers.

Safety Devices for Prevention of Oil Flooding.—Protection against the possibility that the oil-burner mechanism will be operating when the ignition system of the oil burner is not functioning, so that unburned oil fuel will be discharged into the fire-pot, may be obtained in a number of different ways in the several types of oil burners. Installations in all steam and hot-water boilers and warm-air heaters require this kind of protection against flooding by unburned oil discharged from the atomizing nozzles of the oil burner. One of the best methods for the prevention of flooding is to provide an electric time-delay shut-off switch operated by a thermostat (page 5). It may be located in a warm-air heater or in a steam or hot-water boiler in the flue discharging the hot combustion gases into the chimney. Such a switch may however be placed so that its thermostatic element enters the combustion chamber of a steam or hot-water boiler. There is no reason, however, why the electric shut-off

device of this kind should not also be put on the flue through which the hot combustion gases discharge into the chimney of either a steam or a hot-water boiler. In the normal operation of the warm-air heater or of the steam or hot-water boiler, the temperature of the combustion gases in the flue discharging into the chimney increases quite rapidly after the oil burner starts its normal operation. If, for any reason, the atomized oil fuel discharged does not ignite, an electrically operated thermal switch may be used to open the electric-current circuit of the motor that drives the oil burner. If the burner has operated for about 60 seconds (*not more than* 90 seconds), without ignition, and therefore without discharging hot combustion gases into the flue, such a thermostatically operated electric switch will stop the operation of the oil burner.

Oil-regulating Valve.—There should be no flow of oil from the oil pump into the nozzles of a pressure type of oil burner at pressures that are too low to atomize thoroughly the oil fuel. Obviously, at very low pressures in the nozzle—as, for example, when the pressure pump is being started—the pressure in the nozzle may be so low that the oil supplied will simply flow out of the nozzle in drops and will form a pool of oil that will not be burned in the usual way in the burner; because of leakage it may actually become a source of danger. This sort of leakage is especially likely to be troublesome with an oil pump that is operated by an electric motor, as most of them are, for the reason that when the oil burner is started and the circuit is closed on the electric motor driving the pump, some little time is required for the motor and the attached pump to arrive at the normal operating speed; during this low-speed period, the pump will be unable to deliver the oil at a sufficiently high pressure to produce satisfactory atomization at the nozzle of the burner. This, of course, will result in drops of oil accumulating in some part of the oil burner. If, therefore, for the reasons indicated, oil is supplied to a burner nozzle at less than the minimum allowable pressure, part or all of the oil supplied will drip out of the nozzle and form a pool in either the air tube (page 110) or in the firepot in the burner. Without proper regulation as to pressure, the same difficulty will occur below a minimum pressure, when the oil burner is being stopped. It is evident, therefore, that in a pressure-atomizing oil burner, the oil fuel must be delivered to

the nozzle at a constant pressure and means must be provided for the adjustment of this pressure so as to prevent a flow through the nozzle when the pressure developed by the pump is below a minimum value.

Briefly stated, an oil-regulating valve must be provided that will perform the following functions: (1) Deliver the oil fuel to the nozzle of the oil burner only when the oil fuel is delivered by the pump at a sufficiently high pressure to produce atomization; (2) maintain a constant pressure at the nozzle during the operation of the burner; (3) by-pass to the oil-fuel tank or to the suction piping of the pump, any excess of oil fuel that is not needed at the time for the oil burner. An oil-pressure-regulating valve suitable for this purpose is shown in Fig. 87. This regulating device consists really of two valves in the same casing, each valve being closed and opened by the action of a spiral spring. The closing and opening force that is exerted by each spring can be regulated by turning the adjusting screws A_1 and A_2. In the operation of this compound regulating device, the left-hand valve V_1 when open permits the discharge of the oil fuel at the pressure required for the satisfactory operation of the oil burner. The other valve V_2 is provided to regulate a *by-pass* through which any excess of oil that is not needed for the burner may be returned through suitable piping to the oil-storage tank or to the suction intake of the pump. When the oil pump is started, the oil fuel enters the chamber at the bottom of the casing through the intake pipe I, but there is no discharge through either of the valves V_1 or V_2 until a minimum pressure has been developed by the pump. When this minimum pressure is reached, the valve V_1 opens by liquid pressure exerted upward on the valve plunger P_1. As soon as the oil pressure is high enough to overcome the resistance of the spring holding this valve on its seat, the plunger rises so as to open the valve V_1, permitting the flow of the oil fuel into the nozzle of the burner. As the speed of the pump increases,

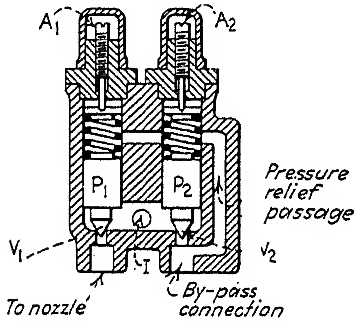


FIG. 87.—Oil-regulating valve.

the oil pressure will continue to rise, and at a predetermined pressure, the right-hand or *by-pass* valve V_2 will be opened in the same way that has already been explained for the valve V_1. When the by-pass valve is open, the excess of oil fuel will pass through piping connected to the oil-storage tank or to the suction piping of the pump. There is a *pressure relief passage* clearly marked in the figure, which permits the discharge into the by-pass connection of any leakage oil that might accumulate in the spring chambers above one or both of the plungers P_1 and P_2. In the operation of this device, the spring pressure on the left-hand valve V_1 must be made high enough to prevent the opening of the valve before the pump has "built up" a pressure that is sufficient for complete atomization. In most pressure-atomizing oil burners, this pressure is about 20 pounds per square inch less than the pressure that operates the by-pass valve V_2. The essential condition, of course, in the regulation and adjustment of the two regulating valves is that the main valve V_1 must always be set for a pressure that is high enough to produce complete atomization. The by-pass valve, on the other hand, controls the working condition of the oil nozzle, and must be adjusted to the pressure at which the nozzle will deliver oil at the rate required for the satisfactory operation of the oil burner. In another type of oil regulator, both valves are kept closed by a single spring. The valve to the nozzle opens first, and when it has reached its full open position, any further compression of the spring allows the by-pass valve to open. The two pressures may be raised or lowered by the spring-adjusting screw, but the difference between them will remain constant.

Pumps.—A type of oil pump that is found in considerable use, for moving the heavy grades of oil, is shown in Fig. 88*a*. In this pump, there are only two moving parts, each of these parts being on a separate shaft. Only one of these shafts is shown in the figure. On the two shafts there are four screw threads which are arranged so that the threads on one screw project to the bottom of the space between the individual threads of the opposite screw. The shaft and screw threads shown in the figure are connected to the source of power and the other shaft is driven from this shaft by "herringbone" gears. There is no internal contact between the rotors and the cylinder as the screw threads on the

shafts do not drive themselves and therefore wear is reduced to a minimum. The pump requires no thrust bearings as obviously the thrust is balanced at the two ends.

A pump intended for lower pressures than the one shown in Fig. 88*a* (preceding description) is shown in Fig. 88*b*. It usually

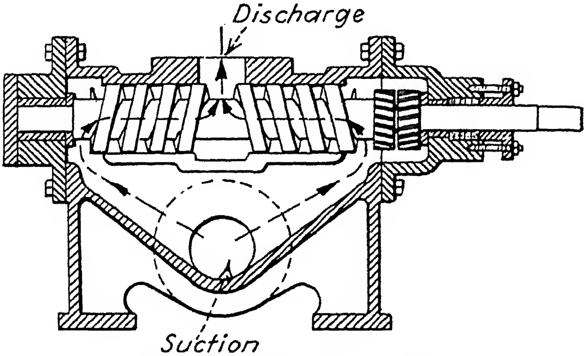


FIG. 88*a*.—Screw-type oil pump.

goes by the trade name "Rotex." In this pump, there are only two moving parts, and the pumping action is produced by two flat-sided elliptical rotors of two-lobe design. There is no metal contact, as the drive is entirely separate from gears not shown in the figure.

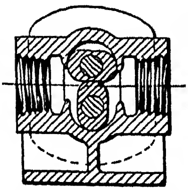


FIG. 88*b*.—Revolving-disk oil pump.

Vacuum-tank System for Oil-fuel Supply.—A vacuum-pump device similar to the vacuum gasoline-feed system at one time quite generally used on automobiles* is applied to supply the oil fuel to some types of oil burners. Such a vacuum pump maintains a partial vacuum in an elevated tank usually attached to a wall above the burner so that there is gravity flow from it to the oil-fuel supply line to the burner, and the action of the mechanism in the tank maintains a constant level of oil. The vacuum necessary for the operation of the vacuum-tank system is supplied usually from a small vacuum pump located conveniently to be driven by the burner motor. Figure 88*c* shows a typical installation of gravity oil feed from a vacuum tank.

* In "Gasoline Automobiles," by James A. Moyer (4th ed., p. 141, McGraw-Hill Book Company, Inc., New York) there are complete descriptions of the operation of a number of types of vacuum-tank syst

Construction of Firepot or "Combustion Chamber" of Oil Furnace.—The shape and dimensions of the firepot, sometimes called "combustion chamber"* of an oil furnace, are really important matters that have a great deal to do with the successful operation of an oil burner. The dimensions that are necessary for the location of the parts of the oil burner with respect to the firepot and the shape and size of the firepot itself are, of course, very important; and the dimensions given for installation should be followed in every case—as nearly as possible. If the firepot

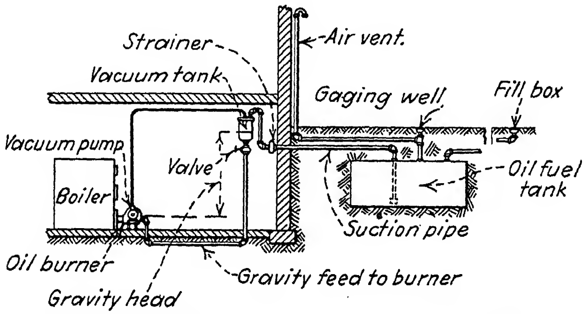


FIG. 88c.—Vacuum-tank system for oil-fuel supply.

is either too large or too small for the size of the oil burner that is to be installed, there is likely to be, in one case, flame impingement (page 41) or, in the other case, excessive cooling of the combustion gases, so that complete combustion will be difficult.

A good layout of a pressure-atomizing oil burner in a sectional boiler showing the location of the air tube (page 110) and refractory brickwork are shown in Figs. 89*a* and 89*b*. In both of these figures, the *air tube A* is shown so that the end from which the nozzle discharges the atomized oil fuel is flush with the inner surface of the brickwork. This is a good arrangement and is much preferable to an installation in which the air tube extends

* The firepot of an oil burner, or more particularly the refractory brick work making up the side walls enclosing an automatic oil burner, is often called, although probably incorrectly, the "combustion chamber." The use of "combustion chamber" in this sense is likely to be confusing, especially to mechanical engineers who ordinarily associate these two words with the space or volume enclosed by the following surfaces: (1) Floor or burner casing below burner; (2) the side and end walls of the firepot; and (3) the crown sheet of the furnace or boiler.

inward beyond the refractory brickwork. In case the flame of the oil burner is too far away from the atomizing nozzle for efficient utilization of its heat, or if the burner flame has a tendency to pulsate, the end of the air tube may be drawn back slightly into the side-wall brickwork. It is desirable to have a curved back wall of the firebox, somewhat like the one in Fig. 89*a*.

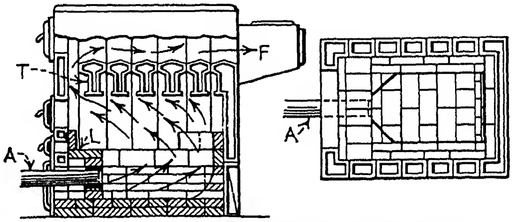


FIG. 89*a*.—Sectional boiler with uptake at front.

This figure shows a good installation design for a steam or a hot-water boiler in which the *uptake T* from the firepot for the discharge of the combustion gases is at the front of the boiler. On the other hand, if the uptake is at the rear of the boiler, the wall of the firepot should be corbeled forward at the top, as shown in Fig. 89*b*. The object of this corbeling is to direct the combustion gases toward the front of the firepot, so that they will pass over the entire heating surface of the boiler in both directions before

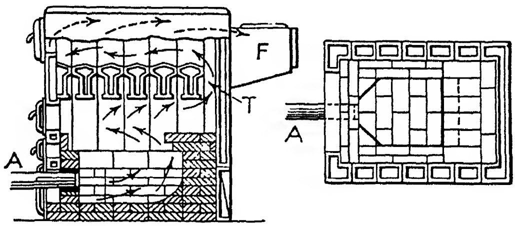


FIG. 89*b*.—Sectional boiler with uptake at rear.

discharging into the flue connection *F*. In Fig. 89*a*, at the front of the firepot, there are angular surfaces which form an L-shaped "pocket" at *L*. Pockets like this are likely to cause eddy currents which may interfere with the effective flow of the hot combustion gases. If, therefore, they are filled so as to make a surface inclined to the horizontal at about 45 degrees, a more efficient firepot is obtained.

The device shown in Fig. 90 is used by one manufacturer for leveling the firepot surfaces of an oil burner.

Gas-generating Oil Burner.—Figure 91 shows a design of oil-fuel burner in which the vaporization of the oil fuel takes place in a generating coil *G*. The gasified vapor thus generated is

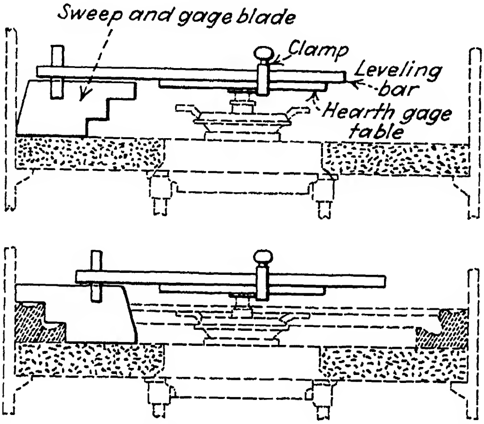


Fig. 90.—Leveling device for use on firepot surfaces.

conducted through a vertical pipe to a control valve *V* from which it discharges through a small orifice under pressure into a venturi-shaped nozzle in which the oil vapor is mixed with the air needed for combustion. Some of this gasified combustible mixture of oil vapor and air is used in the small unit burners *t*, *t*, *t*, *t* which supply the heat for the operation of the generator *G*. This is the

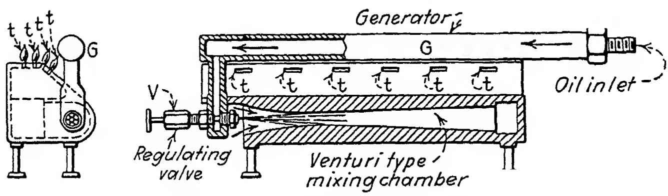


Fig. 91.—Gas-generating oil burner.

same method that is used to obtain combustion in ordinary gas burners. Fuel-oil burners of this type are most commonly used in cooking ranges and in similar appliances of small heat capacity.

Radiant-heat Oil Burner.—The burner shown in Fig. 92 illustrates the use of radiant heat (page 245) from a flame above

the oil. In this burner the oil fuel enters the bottom of the reservoir *retort* through the oil-feed pipe O and is ignited by a gas pilot burner (not shown in the figure). The combustion starts from the surface of the oil in the reservoir R, but the flame produced by the oil-fuel combustion is lifted soon after the operation of the burner is started by the air currents which circulate, as shown by arrows. The oil flame, when thus lifted, is spread out by air discharged from the top of the air distributor D. An additional supply of air for combustion is discharged into the combustion flame through air ports A located around the edge of the retort. This additional air intersects the disk-shaped burner flame at right angles, so that thorough mixing of this air with the

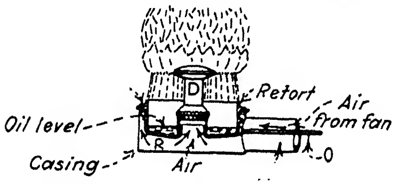


FIG. 92.—Radiant-heat oil burner.

burning vapor is obtained. The heat for vaporization is transferred from the oil flame to the vaporizing liquid oil by *radiation*. The oil is not exposed to excessive temperatures because of the air circulation that is maintained both above and below the oil in the retort reservoir R.

This burner is an example also in its operation of controlled vaporizing temperatures. As the oil flow for combustion is reduced as well as the air supply, proportionally, the heat radiated by the oil flame will be reduced, and the "temperature balance" will be maintained within satisfactory limits. On this type of burner the air-supply adjustments should be made with care, for if the air supply is too large, the temperature of the oil fuel will be reduced below the temperature at which all of it will be vaporized, so that there will be incomplete combustion and accumulation of heavy distillates ("ends," page 16). On the other hand, if insufficient air is supplied to the burner above and below the retort, the cooling effect of this air will be reduced, and the temperature of the oil will be raised so much that there will be thermal decomposition (cracking) of the fuel. The results produced thereby are explained on page 39.

Kitchen-range Burner.—There has been in recent years considerable demand for a portable type of oil burner that could be easily installed in a kitchen range. A typical installation of this kind is shown in Fig. 93. This kitchen oil burner is designed to fit with considerable clearance the firepot of the ordinary type of coal-burning range used in kitchens. It is a simple vaporizing type (page 43), that uses ordinarily a light variety of

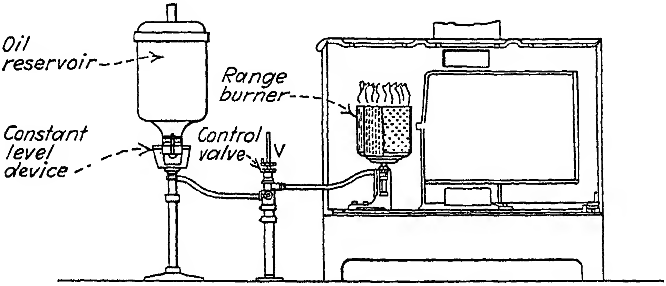


FIG. 93.—Oil-burning range equipment.

fuel oil, which is delivered to the kitchen in large glass bottles. The oil supply shown in the figure is obtained from one of these bottles when inverted, so that it discharges through a constant-level regulator and connecting piping, into the base of the oil burner shown in the range. Between the constant-level device and the oil burner is an *oil-control valve V*, which is used to regulate the size of flame at the burner. Nearly all of the oil-burning range burners are started from a lighted wick which serves to vaporize some of the oil; after the heat from the lighted wick has been continued for a little while, the flame will be lifted from the wick and the vaporized oil fuel will be kept burning by its own heat and flame.

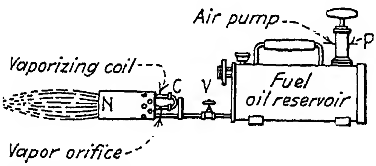


FIG. 94.—Torch type of portable oil burner.

Portable Fuel-oil Burners.—There have been many recent applications of small fuel-oil burners, especially for industrial work, that are suitable for portable use. An example of a portable oil burner of the *torch type* is shown in Fig. 94. In order to start the operation of a torch burner of this kind, it is necessary to apply a hot flame of some kind to the vaporizing

coil C, as shown in the figure. This vaporizing coil is part of the small tube connecting the burner itself with the oil reservoir. Heat applied to the vaporizing coil causes the discharge of combustible vapor from the torch nozzle N and as soon as this vapor appears, it can be lighted with a match or taper. For complete combustion, which is indicated by a bluish flame, the fuel oil in the reservoir must be put under considerable pressure, and

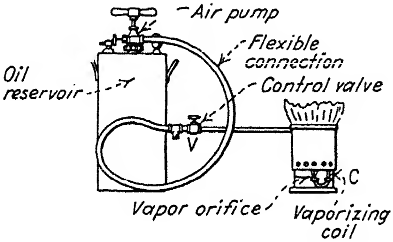


Fig. 95.—Portable oil burner with control valve.

for this purpose an air pump P is provided. The air for combustion enters through the small holes shown in the side of the nozzle N. There is a shut-off valve V.

The portable oil burner shown in Fig. 95 is for ordinary industrial applications. It has practically the same parts as the fuel-oil torch already explained, with the addition of a *control* valve V which is also a part of the torch. In this portable oil burner the vaporizing coil C is shown at the bottom of the right-hand side of the figure.

CHAPTER V

AUTOMATIC-CONTROL DEVICES

Importance of Automatic Control.—In any system of heating by an oil burner, or, in fact, in practically all modern systems of heating, the device used for automatic control of the amount of heat required is most important. The difference in results between a well-designed automatic-control device and one that is cheaply and poorly designed corresponds usually to the difference between comfort and discomfort. A poorly designed device for automatic heat control is in the long run expensive at any price. For this reason, automatic-control equipment cannot be regarded as merely an accessory, and if planned more or less as an afterthought, may make the entire heating system unsatisfactory. In a satisfactory installation, the selection of control devices must be considered in each step of the planning, including the estimating, cost finding, and the actual installation. It is therefore of the utmost importance that the possibilities of satisfactory automatic control should be understood in regard to both actual practice and theoretical considerations. Because of the increasing complexity of oil-burner heating installations, and customer insistence upon evenness in results with respect to both comfort and efficiency, there is an increasing demand for first-class automatic-regulating devices for heating systems.*

Elimination of the Human Error.—From the standpoint of the satisfactory performance of automatic-control operations, it is physically impossible to regulate heating systems by hand as accurately as by automatic means. There are always the

* Most kinds of automatic-control devices used in connection with oil-heating systems are intended for the maintenance of desired or required conditions of temperature, pressure, humidity, air motion or air distribution. This does not imply, however, that all of these conditions must necessarily be controlled in an oil-burner heating system; furthermore, recent practice indicates the desirability of types of automatic control which will permit some fluctuations in the individual factors to the extent that only the final results in terms of comfort, efficiency, and cost of operation are *essentially* important.

possibilities, when depending on manual control, that employees will misunderstand instructions or will be careless as to matters of time and place, in ways that are detrimental to the service, if not actually dangerous. On the other hand, when automatic-control devices are set to operate for definite service conditions, they will almost certainly eliminate the possibilities of error or neglect. Modern automatic-control devices for heat regulation have been so carefully and accurately designed that these devices are, in nearly every respect, improvements over manual control, even by the best trained persons. In this connection, it is notable that temperature-sensitive devices of well-designed kinds will react to changes in temperature much sooner than these changes become apparent by the usual sensory means to an attendant operating similar equipment by hand. It should be clear, therefore, that the results obtained by automatic mechanical regulation are more accurate and reliable than those obtained by manually operated regulation. Particularly in the type of heating system that is most suitable for residential use, the superiority of automatic-control devices over manual control is most important. Doubtless in such installations, automatic-control devices find application for the principal reason that members of the family or others responsible for the heating of the building want to be relieved of the responsibility for constant watchfulness of the heat supply; yet it is generally admitted that a still more important consideration is the fact that automatic-control devices will insure more correct and dependable results with the minimum of attention than could be obtained with the most careful person that can be employed for manual control.

Any automatic-control system must consist of three parts. The *first* of these is a device to produce some *mechanical effect* in response to changes in the condition to be controlled. For example, the ordinary room thermostat moves a blade or lever in response to changes in the temperature of the air. In general, the apparatus to be controlled is at some distance from the controlling device; therefore some means of *transmitting the movement* of the controlling device must be provided. This is the *second* essential part. In the *third* place, some means must be provided to convert the demands of the controlling device into *action by the controlled apparatus*.

Electric-control Systems.—Probably the most satisfactory medium for the operation of temperature- and pressure-controlling devices is electricity. In the general application of electricity in control systems, the method commonly used is the switching on and off, or otherwise adjusting, electric circuits for the purpose of regulating the operation of electric motors, relays, and solenoids. In systems using electric methods of control, it is possible to utilize a number of individual units, all of which may be regulated by central primary controlling instruments. In many systems of this kind, the primary controlling and also the operating units receive electricity at the line voltage of power-distributing systems; but, in most cases, low-voltage supplies can be equally well used. Electric controls are used almost entirely for oil-burner operation.

Pneumatic-control Systems.—For many years, compressed air has been a favorite medium for the operation of temperature-control apparatus. Systems using compressed air for their operation are called "pneumatic." In these systems, one or more centrally located air compressors furnish a supply of compressed air which is distributed in special piping to the various controlling and control devices. By means of so-called "leak" parts or orifices, the pressure of the air is varied in the branch lines and the changing pressures are utilized to accomplish variable openings of the valves and dampers that are controlled by the compressed air lines to obtain the movement necessary to the operation of valves and dampers in the heating and ventilating system.

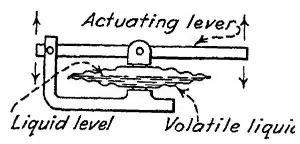


FIG. 96.—Diaphragm typ of thermostat. (*From* "*A.S.H.V.E. Guide* 1936," *Chap.* XIV.)

Types of Thermostats.*—Although there are many types of thermostats that are responsive to temperature changes, the basic principles of operation of practically all of them are illustrated in Figs. 96 to 100.

Figure 96 is an example of the *diaphragm* type, which operates by the expansion of a liquid or gas within a diaphragm or bellows (page 143). The movement of the diaphragm produced by this expansion is transmitted mechanically in proportion to the rise and fall of the air temperature surrounding the diaphragm.

* For a more extended explanation of these types see "A. S. H. V. E. Guide 1936," pp. 269–279.

Figure 97 is an example of the *bimetallic type* which is operated by the movement produced by the heating or cooling of a flat strip constructed of two materials placed side by side, usually metals that have dissimilar coefficients of expansion. This

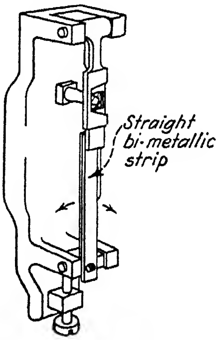


FIG. 97.

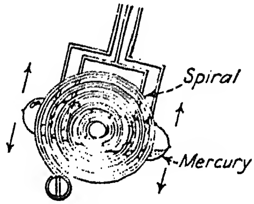


FIG. 98.

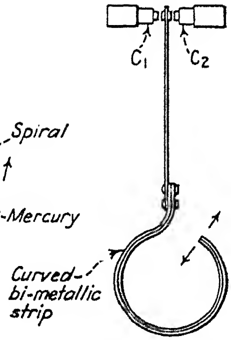


FIG. 99.

FIG. 97.—Straight-strip type of bimetal thermostat. (*From* "*A.S.H.V.E. Guide* 1936," *Chap.* XIV.)
FIG. 98.—Spiral type of bimetal thermostat. (*From* "*A.S.H.V.E. Guide* 1936," *Chap.* XIV.)
FIG. 99.—Curved-strip type of bimetal thermostat. (*From* "*A.S.H.V.E. Guide* 1936," *Chap.* XIV.)

type is, as a rule, more sensitive to temperature changes than the diaphragm type (Fig. 96), but lacks the necessary *force* to cause movement of the control equipment; it must therefore be used with compressed air, electric current, or some other source of power. The sensitive element may take any one of a number of forms; the most common are the *straight strip* (Fig. 97) used in most compressed-air thermostats; the *spiral* type (Fig. 98) used in a mercury-tube thermostat (page 148), and the *curved strip* (Fig. 99) used in "open-contact" thermostats.

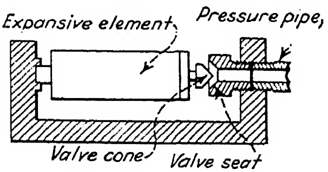


FIG. 100.—Direct-expansion of thermostat.

Figure 100 illustrates a *direct-expansion* type of thermostat which operates by the direct expansion and contraction of a metal or fiber with a high coefficient of expansion such as that of hard rubber. The slight movement of the thermostatic element in a thermostat of this kind must usually be multiplied by a suitable system of levers to produce the desired mechanical movement.

Bimetal Temperature-control Elements.—Probably the most popular actuating mechanism of the room-thermostat type is the one that operates by the difference in expansion of two dissimilar metals. The bimetal element is formed into flat strips (Fig. 97) or spirals (Fig. 98). It consists in either case of two metals welded together that have different coefficients of expansion. Because of having different coefficients of expansion, one of the metals will expand to a greater extent than the other, and, as a result, there will be a bending of the welded strip, and thereby the development of a force which may be utilized to actuate contacts in the electric controls or of the variable orifices in the pneumatic system.

Corrugated-metal Bellows or Flexible-diaphragm Operating Element.—A large variety of temperature-regulating devices utilize in some form a small metal bellows or flexible diaphragm (shown in Fig. 96). In the application of these devices, the method commonly employed is to fill a tube and a corrugated metal bellows or flexible diaphragm that is connected to it with some highly expansive liquid or gas. When this expansive liquid or gas is heated, internal pressure is generated which has the effect of increasing the inside volume of the folds of the corrugated-metal bellows or the cubical contents of the container that is made with a flexible diaphragm for one of its walls. The internal pressure thus produced is sufficient to cause the movement of levers connected to the corrugated-metal bellows or of the flexible diaphragm, and also of electrical contacts or of adjustable orifices that may be linked up with them. In the design of temperature-control devices, the corrugated-metal bellows is generally preferred to the flexible diaphragm for the reason that it gives a greater amount of movement of the parts.

Rod-and-tube Controls.—Closely allied to the bimetal types of thermostats and temperature controllers are those which use the rod-and-tube construction. A rod of metal or carbon is fastened to a scaled tube of metal having a different coefficient of expansion. This attachment is only at one end, so that when the assembly is subjected to changing temperatures, the rod and tube expand at different rates, thus providing motion and power with which the electrical contacts or air (pneumatic) orifices can be operated.

Control devices are often employed with the object only of providing a safety device to limit the maximum pressures and temperatures in boilers and other types of heaters. Oil-burner equipment which must be started or stopped in a definite sequence in order that the oil burner may operate without hazard, is typical of most modern designs. This safety measure may be illustrated by the circumstance that an oil-burning system must not under any circumstances discharge oil in vapor or liquid form into the firepot of a steam or hot-water boiler or warm-air heater, unless an ignition pilot light (usually supplied with gas) or an electric-spark-ignition device is in proper working order.

High-low and Graduated Controls.—In most cases the thermostat provides for intermittent operation of the burner, that is, the burner operates at full capacity or is entirely shut off as the demand for heat increases or decreases; but there are exceptions. One of the exceptions is the so-called "high-low" burner control which provides practically intermittent control. The "low" flame is simply an oil pilot light to take the place of the gas- or electric-ignition device which is necessary with intermittent control.

Another exception is "graduated" control which increases or decreases the size of the flame in response to the demands of the thermostat. The burner is only shut off or brought to the lowest flame condition when no heat is needed. Graduated controls are of two types, "step-by-step" graduation and "continuous" graduation. A step-by-step-controlled burner may operate at one of several definite rates between a maximum and either a minimum or zero. The thermostat selects the "step" or size of flame which most nearly meets the heat demand at any particular time. Continuous graduation is equivalent to an infinite number of steps; that is, when the thermostat requires more heat, the flame is increased only enough to meet the actual demand instead of making a "jump" such as occurs from on-and-off operation.

Obviously, graduated control should provide more satisfactory conditions than intermittent control. However, the former presents a number of complications both in the control system and in burner design, and the comparative *simplicity of intermittent control has resulted in its almost universal use.*

Mercury Switch Type of Limit Controls.—Various limit controls are illustrated in Figs. 101 to 104. They are intended simply to open and close a *mercury switch* as the temperature (or pressure) rises and falls. The mercury switch, shown in Fig. 101 (and also in Fig. 98), is a small glass tube, hermetically sealed, and containing a large drop of mercury. The two switch wires pass through the glass at one end of the tube. If the tube is tipped so as to slope downward to the right (Fig. 101), the drop of mercury moves to that end and covers the bare ends of the wires, thus closing the circuit. If the tube is now turned so that it is inclined downward toward the left, the mercury drop moves toward the left, uncovering the ends of the wires and opening the

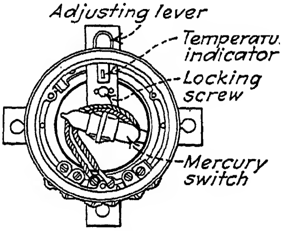


FIG. 101.—Mercury switch.

Although the motion of the tube is usually very gradual, the mercury will move quickly at the instant when the tube reverses its inclination. This gives a quick make or break of the circuit and reduces the sparking tendency. To prevent oxidation of the wires and of the mercury from such sparking as does occur, the air, and therefore the oxygen, is exhausted from the tube. In many cases the tube is then filled with some inert gas, such as nitrogen.

Any device containing a mercury switch must be set level. The movement of the drop of mercury takes place when the tube passes through the level position. Therefore, if its case is tipped to the right or left, the instrument will not respond to the proper pressure or temperature. A slight tipping forward or backward will not affect the operation. A leveling pendulum is shown at the right side of Fig. 104. This is a metal strip swinging freely on a pivot which is just behind the right-hand end of the mercury tube. The bottom end of this pendulum is cut to a point, and below the point is an index mark on the case. The instrument should be mounted so that the point of the pendulum hangs directly over the index mark.

Aquastat.—An "immersion" type of aquastat is shown in Fig. 102. The tube extending from the back of the case is closed at the outer end, and the thread shown is a $\frac{3}{4}$-inch-pipe thread. This is screwed into a tee in the water piping or into a tapped hole

in the heater shell, so that the tube extends into the water. Inside the tube is a bimetal thermostatic element. Movement of the element, caused by changes in temperature of the water, rotates a shaft which in turn tips the mercury switch. Adjustment of the operating temperature is accomplished by changing the position of the tube with respect to the shaft. On an aquastat this can be set at any point between 60° and 210°F. However, these limits may vary with different types and makes of instrument. A differential (page 160) between the "cut-in" and "cut-out" can be obtained if "lost motion" is provided in the connection between the tube and the shaft.

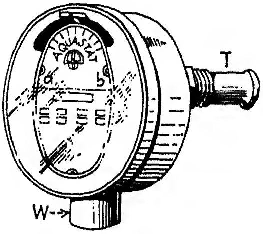


Fig. 102.—Immersion type of aquastat.

In the "surface" type aquastat the thermostatic element is inside and in intimate thermal contact with the back of the case. The instrument is mounted by clamping it to the water pipe so that the back of the case is held tightly against the pipe. Temperature changes of the water are transmitted through the metallic wall of the pipe and the metallic back of the case to the thermostatic element.

Airstat.—A view of an airstat (for use in a warm-air heater) is shown in Fig. 103. It differs from the immersion type of aquastat in two respects. The airstat thermostatic tube is longer so that it extends well into the bonnet of the furnace. The operating range is higher than for the aquastat, usually from 100° to 500°F.

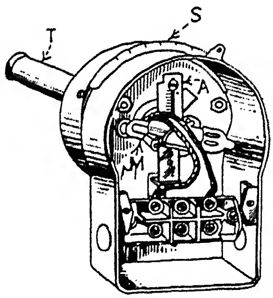


Fig. 103.—Airstat.

Pressurestat.—Figure 104 shows a simple type of pressurestat. A rise in pressure expands a metal bellows in the cylindrical casing at the bottom of the instrument. This motion, acting through a lever mechanism, tilts the mercury switch. The operating pressures are regulated by the two springs shown at the left. The larger spring controls the "cut-in" pressure, that is, the pressure at which the switch closes. The differential between the "cut-in" and "cut-out" pressures is controlled by the smaller

spring. Both springs can be easily adjusted by means of the screws which extend through the top of the case. One make of pressurestat is designed for a "cut-in" gage-pressure range of zero to 10 pounds per square inch, and a differential range of from ½ to 6 pounds per square inch. In other words the "cut-out" pressure can be set at any point between ½ and 6 pounds *above* the "cut-in" pressure, whatever that may be, and the latter can be set at any point between zero and 10 pounds. Pointers attached to the adjusting screws travel over scales on the left side of the case and indicate the settings.

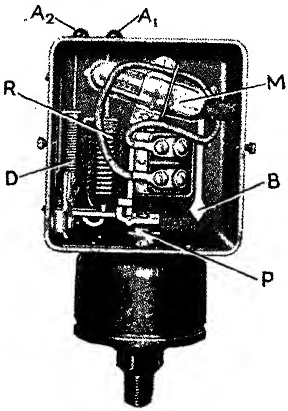


FIG. 104.—Typical mercury switch. M is
P is bellows
pendulum level indicator; R is range adjusting spring; D is differential adjusting spring; A_1 is pressure adjusting screw; A_2 is differential adjusting screw.

The usual method of mounting a *pressurestat* is shown in Fig. 105. The word "pressuretrol" is the trade name for a pressurestat. A *syphon* or "pig-tail" is made by bending a piece of ¼-inch pipe into a loop, and the pressurestat and gage are connected to this syphon as shown. The loop of the syphon is filled with water, which acts as a seal to prevent hot steam from entering the instruments and destroying their sensitiveness. If the loop of the syphon extends to the right or left of the pressurestat that has a mercury switch, the latter will be thrown out of level by the expansion of the loop with temperature changes. The pressurestat should be braced or supported independently of the syphon to avoid vibration.

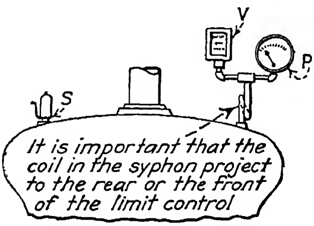


FIG. 105.—Syphon for mounting pressurestat.

Details of the expanding bellows type of mercury switch are shown in Fig. 106, and the action of the drop of mercury in Fig. 107.

Mercoid Air-type Thermostat.—The mercoid thermostat shown in Fig. 108 is operated by means of an extremely sensitive

bimetal thermostatic spiral G in conjunction with a permanent magnet B and a so-called (mercoid) mercury switch or pocket D. This switch remains fixed in position and operates by magnetic

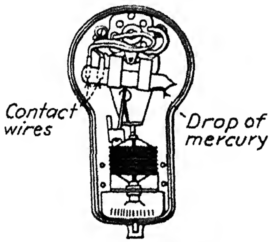


FIG. 106.—Details of bellows-operated mercury switch.

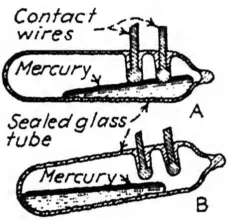


FIG. 107.—Action of mercury in mercury switch.

attraction upon the armature A through the glass as illustrated diagrammatically with a slightly different arrangement of the parts in Fig. 109a. When the temperature of the air surrounding the thermostat is low, the bimetal coil G holds the magnet B so close to the side of the glass that it attracts strongly the armature A; and in that case the magnetic attraction through the glass serves to keep the electric circuit closed through the electrodes C and E (Fig. 109b) and the mercury in the well D. As the temperature rises, the bimetal coil G moves the magnet B away from the switch so that the armature A is released and the electric switch opens as shown in Fig. 109a with the electrode E out of liquid contact with the electrode C through the mercury so that the electric circuit through these two electrodes is open.*

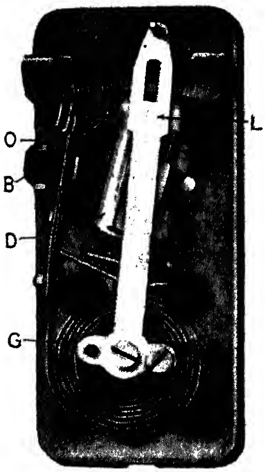


FIG. 108.—Penn thermostat showing essential parts.

A typical mercury switch used to operate a safety gas pilot light is shown in Fig. 84 (page 116).

Connections for Limit Controls.—The function of any limit control is to shut down the burner when the pressure or tem-

* This action of the mercoid thermostats is reversed in those intended for refrigerating systems.

perature in the heater exceeds a certain value, no matter what the demands of the thermostat may be. As long as the pressure or temperature is below that for which the limit control is set, the thermostat must be in complete control of the burner. Stated

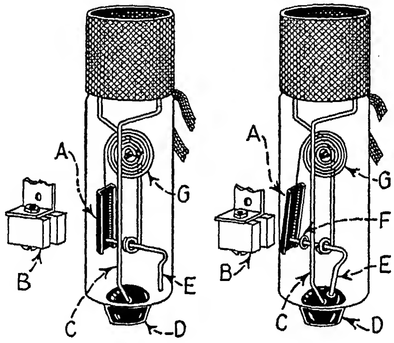


FIG. 109*a*.—Penn mercoid thermostat with open circuit.
FIG. 109*b*.—Penn mercoid thermostat with closed circuit.

in another way, either the thermostat or the limit control can shut down the burner; both must operate to demand heat if the burner is to run.

Limit controls may be connected either in the low-voltage circuit or in the high-voltage supply line. In the first case the connections must be made as shown in Fig. 110. The limit control is in series with the thermostat and the control panel. One piece of three-wire cable connects the thermostat to the limit control so as to connect the binding posts, red to red, white to white, and blue to blue. A second piece of cable connects the limit control to the control panel in the same way.

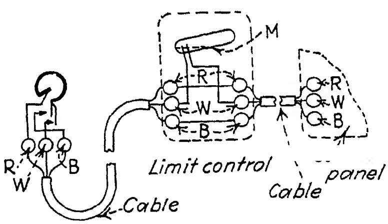


FIG. 110.—Low-voltage connections for limit control.

As shown in Fig. 110, the two red binding posts of the limit control are connected by the internal wiring, and likewise the two blue posts, while the *mercury switch* makes or breaks the connection between the two white posts. It is obvious that

the same effect would be obtained by leaving the red and blue wires of the cable intact, disconnecting the white wire, and connecting the disconnected ends to the limit control. The arrangement shown simplifies the work of installation.

When the mercury switch is open, the white line is broken and the burner can be neither started nor continued in operation. When this switch is closed, the circuits are under the control of the thermostat just as they would be if no limit control were used.

Connections with the limit control in the high-voltage circuit are shown in Fig. 111. In this case the limit control opens the "hot" wire in the main supply line, cutting off the power supply to the entire equipment. Many authorities prefer this method of connection as offering more certain protection. With the arrangement of Fig. 110 the limit control simply opens the relay holding circuit. It is possible, of course, that the relay may

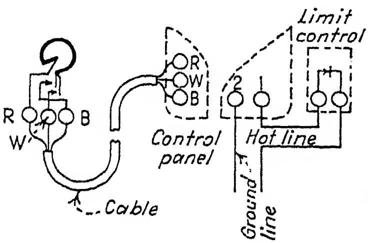


FIG. 111.—High-voltage connections for limit control.

in the closed position when the holding current is interrupted. In such a case the limit control, if in the low-voltage circuit, will not operate.

"Cold Seventy."—One of the most troublesome features of oil heat is what is usually called "cold seventy." During the periods when the burner is not running the occupants of the room are likely to experience a sensation of coolness, especially around their feet and ankles. This is partly due to the so-called "overshooting." Suppose the thermostat is set to start the burner at 70°F. and stop it at 72°F. The thermostat can only act when the temperature of the sensitive element changes. A variation in air temperature across the room can have no effect. Also after the burner starts, some time must elapse before its effect reaches the radiator and the air of the room. During this time the air temperature continues to fall in some cases quite an appreciable amount. A similar effect takes place on the upswing. The room temperature continues to rise for a time after the burner is shut down.

Convection air currents are much more likely to cause "cold seventy" than "overshooting." When any of the air in a room

comes in contact with a hot radiator, it is warmed, becomes lighter, and rises toward the ceiling. Similarly, air in contact with the cold outside wall, or more especially the windows, is cooled and falls toward the floor. The air currents thus set up are called *convection currents.*

A vertical cross section through a room is shown in Fig. 112. The radiator is located under a window with the thermostat on the opposite inside wall. If the radiator is full of steam the general direction of the *convection currents* is indicated by the dotted lines. Air heated by the radiator rises, flows along the ceiling toward the inside wall, drops to the floor, and flows toward the radiator. As the heated air travels through and

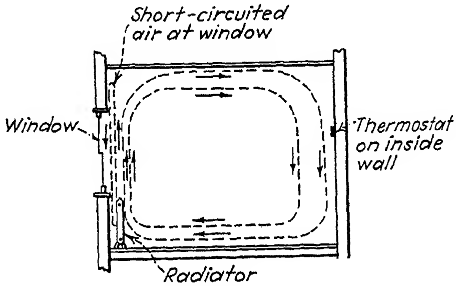


FIG. 112.—Convection currents in room around heated radiator.

around the room, it gives up some of its heat to the walls or any other objects it comes in contact with. A second set of convection currents operates between the radiator and the outside wall. The air in contact with this wall is cooled much more than that circulating over the inside walls. This chilled air drops rapidly, but before it can travel across the floor, it is heated by the radiator and rises.

It must be understood that the dotted lines of the illustration indicate only the general tendency of the convection currents. Various irregularities cause all sorts of cross currents to modify the main flow. However, the strongest currents will be more or less as shown. The air in the upper part of the room will always be warmer than that near the floor, but with properly located radiators comfortable conditions are possible.

If the radiator becomes cold as frequently happens during an "off" period of the burner, the main convection currents are

reversed as shown in Fig. 113. Here the air, chilled by contact with the outside wall and window, is free to flow across the floor. The inside wall, being now probably the warmest surface in the room, sets up a rising current, but this effect is comparatively

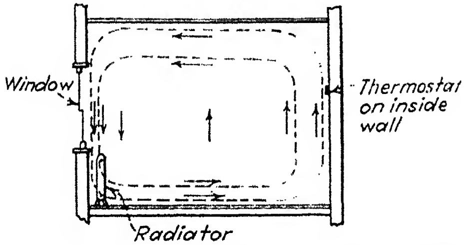


Fig. 113.—Convection currents in room when radiator cools.

slight. The nearer the window the more rapid the circulation will be, and the faster the air temperature will fall. Long before the cooler air reaches the thermostat it is circulating over the people in the room and producing the feeling of chilliness.

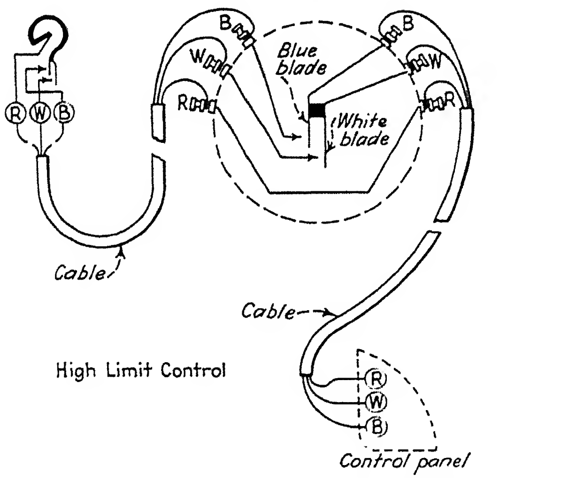


Fig. 114.—First method of electric connections for high-limit control.

Low-limit and High-limit Controls.—A number of different arrangements have been developed to lessen the effect of "cold seventy." One of these is called a "low-limit" control. It is

designed to start the burner as soon as the radiator temperature drops to a certain low limit, even when the thermostat does not demand heat.

One form of such a control is made as a surface-type aquastat, as an immersion-type aquastat, and as an airstat, the electrical operation of all three forms being the same. It may also be used as a limit or, as sometimes called, a *high-limit control.*

Two arrangements of this control are shown in Figs. 114 and 115. The thermostat element carries two blades, a white *W* and a blue *B*, which operate in the same way as the blades in the room thermostat explained on page 149. In this device the *two blades are electrically insulated from each other*. There are two groups of binding posts, those on the left marked "From Thermostat," and those on the right "To Relay."

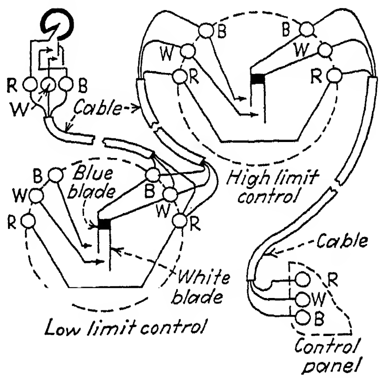


FIG. 115.—Second method of electric connections for high-limit control.

In Fig. 114 this device is shown connected as a high-limit control, that is, in series with the thermostat. With low-water temperature the blue and white blades are closed against their contacts, and the burner is under control of the thermostat. When the temperature rises far enough to open the white contact, the burner is shut down and cannot start again until the white and then the blue blades are closed. Note that the two red posts are electrically connected through the instrument.

For use as a low-limit control the instrument is connected as indicated in Figure 115. Two aquastats are shown, the one in the upper right-hand corner of the figure acting as a high-limit control. It is connected, and operates, in the same way as that shown in Fig. 114. The low-limit aquastat may be mounted on the heater, on the circulation main, or on one of the radiators. If used with a steam system, it is mounted on a radiator. The cable from the thermostat is wired to the binding posts marked "To Relay" and another cable from these same posts leads to the high-limit control. (Obviously the same effect would be

obtained if the thermostat cable were connected directly to the high-limit control.)

The low-limit control must start the burner, independently of the thermostat, when the water (or radiator) temperature drops below the selected point. Since the white and blue blades are insulated, it is necessary to connect together the three binding posts on the left of the instrument (those marked "From Thermostat").

With the connections as shown, and the low-limit control set for, say, 120°F., the burner will maintain that temperature in the heater or in the radiator. Thus the radiator is never cold

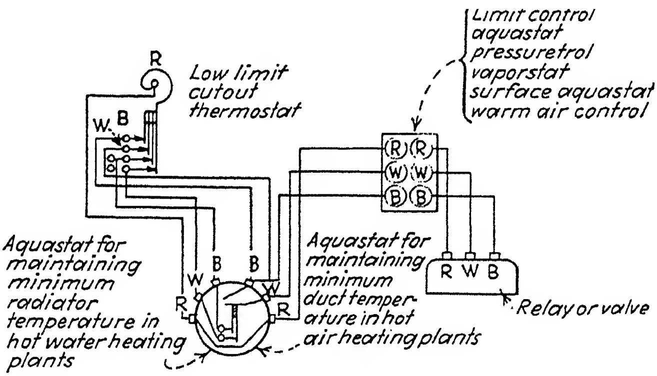


FIG. 116.—Connections of low-limit cut-out thermostat.

and the reverse convection currents, indicated in Fig. 113, cannot be set up.

Objection may be made to this arrangement because it starts and stops the operation of the oil burner much more frequently than other methods. However, it does improve the comfort conditions by reducing the "cold seventy" and also provides quicker responses to the demands of the thermostat. A more serious objection is that the rooms will be overheated in very mild weather. This can be overcome by adjusting the low-limit control to its "off" position in mild weather and readjusting as colder weather comes on. This can be accomplished automatically by the use of a "low-limit cut-out thermostat" connected as shown in Fig. 116. This thermostat has *four* blades, the two extra ones designated as "green" and "orange." These

two blades are set to open and close at temperatures about 2°F. above those at which the blue and white blades act.

High- and Low-limit Controls for Domestic Hot Water.—There are two methods of heating the domestic water supply from the oil burner. The direct heater consists of a pipe or coil in the combustion chamber. This arrangement is never very satisfactory and under some conditions is actually dangerous. A much better arrangement is by use of an indirect heater as shown in Fig. 117.

The *indirect heater* is a small cast-iron tank or shell which is connected to the steam boiler as shown in Fig. 117. The upper

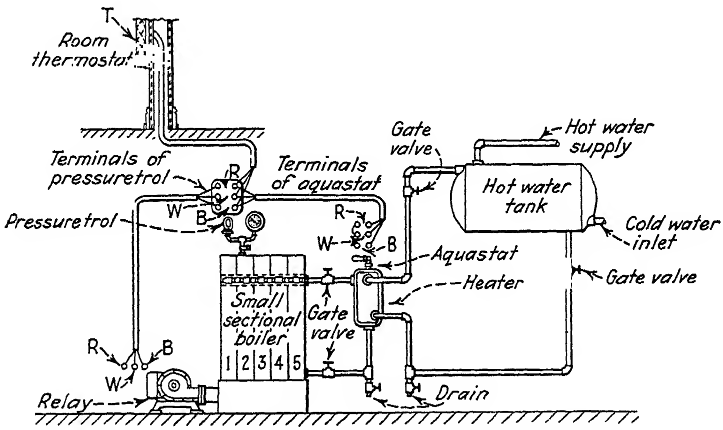


Fig. 117.—Indirect heater control for domestic hot water.

connection is just below the lowest boiler-water line and the lower at the bottom of the boiler. The domestic water circulates through a coil inside the heater shell so that it is not mixed with the boiler water. In a cast-iron sectional boiler the upper connections between sections are above the water line. Therefore the upper circulating pipe to the indirect heater *must be tapped into every section of the boiler.*

If the oil burner is to supply domestic hot water only during the heating season, no extra controls are required. The domestic water can never become hotter than, and because of radiation losses never as hot as, the boiler water. Therefore no dangerously high pressures or temperatures in the domestic supply are possible. In mild weather the oil burner may not run often

enough to supply the hot-water demand; therefore some auxiliary heating device must be provided.

Summer-winter Control.—By the use of summer-winter control with an indirect heater, the oil burner can provide domestic hot water at all times and steam for the heating system when, and only when, demanded by the room thermostat. This control is simply a low-limit aquastat installed in the water circuit between the boiler and the indirect heater. This is shown in Fig. 117 inserted in the top of the indirect heater but is sometimes placed in a tee in the upper pipe between the heater and the boiler, or

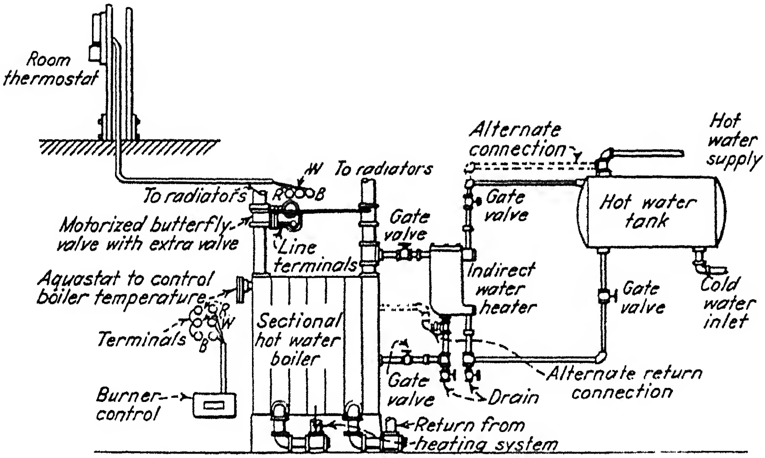


FIG. 118.—Summer-winter control for domestic hot water.

even in the boiler itself below the water line. Sometimes a surface-type aquastat is used on the circulating pipe. The electrical connections are exactly as shown in Fig. 115.

The aquastat is set to maintain 160° or 180°F. (never above 200°F.) in the boiler water. This will heat the domestic water but will not supply any steam to the heating system. When the room thermostat demands heat, steam will be made, and the heating system will operate normally. This "summer-winter" control does not interfere with the operation of a low-limit control on the heating system.

In selecting an indirect heater it should be noted that the commercial ratings are on a three-hour basis. For example, a heater rated at 30 gallons will require 3 hours to heat that quantity of

water. Data for estimating the hot-water demand are given on page 299. It is well worth while to cover the hot-water storage tank with insulation.

With a heating system using hot water instead of steam the domestic water may be heated by an indirect heater. However, the summer-winter control must be modified since any rise in temperature of the boiler water will cause circulation and so supply heat to the house. The arrangement is shown in Fig. 118. Here the room thermostat has no connection with the burner but simply opens and closes a *motorized valve* in the riser (or risers) from the boiler. When no heat is required, this valve is closed, positively preventing circulation to the radiators. The burner is controlled by an aquastat inserted in the boiler as shown in Fig. 118. This aquastat must be inserted in the boiler, *never in, or on, the riser.* If an aquastat is used, the three terminals marked "From Thermostat" must be connected together as shown in Fig. 115. Obviously this aquastat acts as a high-limit control as well as a main burner control. It must be set at the temperature necessary to carry the house heating load.

Control Relays.—In some cases, the primary controlling device, as, for example, a thermostat, is not sufficiently strong in its action to move electric switches, valves, dampers, or shutters that are to be operated by automatic means. In that case a relay device may be connected between the thermostat or any other relatively weak controlling device and the part of an oil burner that is to be moved, in such a way that the small force available for movement of the control device is multiplied a large number of times and to such an extent that the controlled device is then easily moved. For example, a thermostat must usually be constructed of such light-weight parts in order to be sufficiently sensitive to changes in temperature that it is not capable of developing sufficient power to operate electric switches, valves, or dampers. It is therefore the practice to use a relay connected, on the one hand, with the delicate parts of the thermostat and on the other hand with the more rugged parts of the controlled device that is to be moved. By this method, the thermostat will actuate the relay and the relay in turn will move the switches, valves or dampers to which it is connected. When a relay system is applied, the *thermostat* may usually be at a considerable distance

from the parts that are to be operated, but there are obvious advantages in having the *relay* close to the parts that are to be moved.

Thermostat Connections.—A thermostat operating with a relay device is shown in Fig. 119. The thermostatic element is made of two curved strips of metals with different rates of expansion. The thermostat belongs, therefore, to the bimetal classification. The two different metal strips are welded together, back to back, and are then bent into the shape shown in the figure. The end A of the thermostatic element T is fixed to the piece B which is pivoted to the frame of the instrument at P, but is prevented from turning by the eccentric adjusting screw S. A reduction in temperature causes the curvature of the element to increase, thus moving the free end F toward the left. Attached to the free end of the element are two metal blades labeled "white" and "blue," which make and break the circuits at the contacts C_1 and C_2. The instrument is adjusted so that the white blade touches the contact point C_2 before the blue blade touches the contact point C_1. With rising temperature the blue blade breaks contact first and then the white blade.

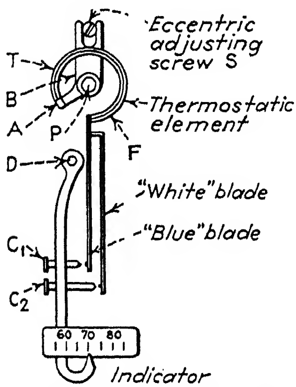


Fig. 119.—Electric connections of thermostat operating a relay.

The contact points of the thermostat are carried on a support which is pivoted to the thermostat frame at D. As the indicator of this support is moved to the left or right over the graduated temperature scale, the contact points are similarly moved in order to lower or raise the temperature at which the contact is made. By means of an eccentric adjusting screw the thermostatic element T and its attached blades may be moved to the right or left to make the actual operating temperature correspond to the indicator scale.

A three-wire cable is used to connect this thermostat with the operating device, usually a relay, and the individual wires are distinguished by different-colored insulation. The colors red, white, and blue are commonly used; hence the use of the terms

blue and white to distinguish the blades. Binding posts are colored to correspond or are marked with letters *R*, *W*, and *B*, to correspond to the colors red, white, and blue, respectively. In this type of thermostat the red binding post is always connected to the thermostatic element and through it to the white and blue blades.

A diagram of a simple control system is shown in Fig. 120. This consists of a transformer (page 122), a thermostat, and a relay. Two switches, marked S_1 and S_2, are operated by the relay. They are held open by gravity until current flows through the relay coil and then the magnetic pull of the coil closes them.

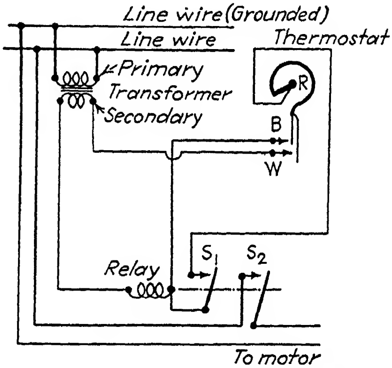


FIG. 120.—Diagram of simple control system including transformer, thermostat, and relay.

Starting with conditions as indicated in Fig. 120, if the temperature at the thermostat is reduced, the blades will swing to the left, closing the white contact *W* and then the blue contact *B*. This establishes the relay or holding circuit. In Fig. 120 this circuit may be traced from the white contact *W*, through the secondary coil of the transformer, through the relay coil, to the blue contact *B*, and through the corresponding blades of the thermostat back to the white contact *W*. The closing of this relay or holding circuit allows current to flow through the relay coil causing sufficient magnetic pull to close the two switches S_1 and S_2.

As shown in Fig. 121 the motor is supplied with full line voltage through the switch S_2. On the other hand the switch

S_1 closes a second return path for the current from the relay coil to the thermostat.

When the temperature rises, the thermostat blades move toward the right, first opening the blue contact B. This does not break the relay or holding circuit since the current can still flow through the switch S_1, the red wire, and the thermostat blades back to the white contact W. Further rise in temperature opens the white contact which breaks the relay or holding circuit, so that the switches S_1 and S_2 are released, the motor stops, and conditions are again as shown in Fig. 120.

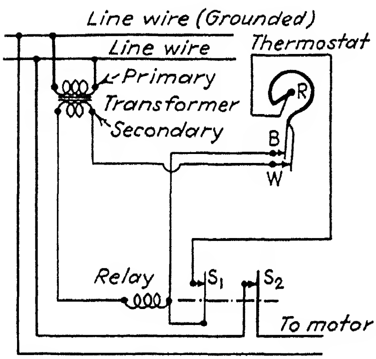


FIG. 121.—Diagram showing operation of switches in Fig. 120.

There are several important points to be noted in connection with the foregoing operations. *First*, the thermostat makes and breaks the circuit of the secondary coil of the transformer, which carries always a low voltage (usually 12 volts). The normal motion of the thermostat blades is slow and excessive sparking would occur at the contacts if supplied with current directly at the line voltage (110 volts or more), especially when breaking the circuit.

Second, there is always a definite difference called the *differential*, between the temperature at which the motor is started and that at which it stops. *If only one blade were used* on the thermostatic element to make and break the circuit, the motor would start and stop with very small changes in temperature. Motors take more current when starting than when running, and no oil burner operates efficiently after starting until the flame has been properly established. Therefore too frequent starting and stopping is objectionable. Most thermostats are adjusted to give a differential of 2°F. between the starting and stopping temperatures.

Third, it will be observed that the blue and white lines must be closed to *start* the motor, the red and white lines must be closed while the motor *runs*, and the white line must be opened to *stop* the motor. For example, a pressurestat (page 146) on a steam

boiler may be arranged to operate independently of the thermostat so as to break the white-wire circuit between the relay and the thermostat. Then if the pressure becomes too high, the switch in the relay or holding circuit is opened and the motor is stopped, no matter what the position of the thermostat may be. When, however, the pressure in the boiler is reduced again below the pressurestat setting, the switch is closed and the white-wire circuit and the motor are put back under the control of the thermostat.

In Fig. 122 the actual wiring arrangement for such a system is illustrated. Electrically, this is exactly the same system as

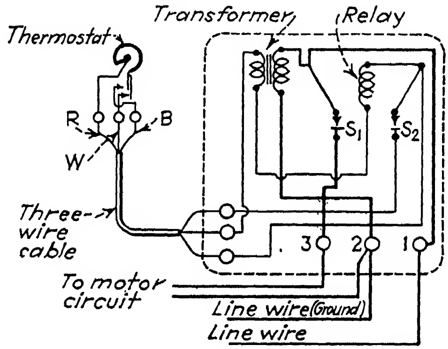


FIG. 122.—Wiring diagram of typical relay panel.

that of Figs. 120 and 121. The dotted line in Fig. 122 indicates the boundary of the relay panel, and all wiring and apparatus inside this boundary are assembled at the factory. This includes the transformer, relay coil, relay switches S_1 and S_2, and the wires indicated. The three binding posts indicated by the numbers 1, 2, and 3 are for the line-voltage connections. The "hot-line" wire (page 121) is connected to binding post 1, the ground wire and the return wire from the motor to binding post 2, and the "hot-line" wire to the motor to binding post 3. The red, white, and blue wires of a three-wire cable are connected to the low-voltage binding posts *R*, *W*, and *B*, respectively. The circuits in Fig. 122 are the same in action as described above for Figs. 120 and 121.

Combustion Control.—The term "ignition failure" is applied to the failure of an oil burner to establish the flame when the mechanism of the burner starts by the closing of the operating

circuit by the thermostat. The term "flame failure" applies to the case where, the flame having been established, is soon extinguished. In either case the burner must be shut down to avoid flooding at least the firepot with the oil fuel. Such a safety shut-down is usually accomplished by opening the white-wire circuit when the temperature in the combustion chamber or in the smoke pipe is below the normal value it should have when the oil burner is operating properly. The smoke-pipe temperature is always low before the burner starts, and therefore, for a normal start, provision must be made to delay the action of the safety shut-down or combustion control until the normal temperature is attained.

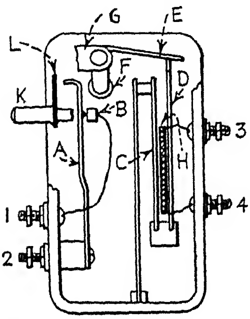


Fig. 123.—Heat-operated safety shut-down switch.

A heat-operated *safety shut-down switch* is shown in Fig. 123. In this device a flexible switch blade A makes connection with the semifixed contact B. The binding posts 1 and 2 are connected in series in the white-wire circuit from the thermostat so that the current in this wire must flow through binding post 1, contact B, blade A, and binding post 2. Binding posts 3 and 4 are in the relay or holding circuit so that this current must flow through these binding posts and the heating element marked H. A roller F is carried on an arm which is pivoted to G which is part of the frame of the device. The blade E is part of this arm. The outer end of the blade E is supported by the end of the blade D. When current passes through the heater H, it raises the temperature of the blades C and D, which causes the upper end of D to move toward the right.

There is a slot in the blade E near its outer end; and when the end of the blade D reaches this slot, the blade E drops down over D, swinging the roller F to the left and forcing the contact blade A away from contact B. This opens the white-wire circuit from the thermostat and stops the operation of the burner. After such a safety shut-down the burner cannot start again until the reset button K is pushed in and released.

In Fig. 124 the essential parts of the device are shown in several assumed positions. In the diagram of Fig. 124 the parts are in their normal positions, the switch contacts A and B are closed

and the blade *E* is supported on the end of the blade *D*. In diagram of Fig. 125, the blade *D* has been forced to the right by the action of the heater *H*, and the blade *E* has dropped, swinging the roller *F* to the left and opening the contacts.

The reset button *K* carries the insulating plate *L* and also an arm (shown broken off between *L* and *A*), which supports the contact *B*. When the button *K* is pushed in, the plate *L* forces the upper end of the blade *A* to the right, raising the blade *E* and allowing the blade *D* to snap back to its normal position. However, this motion of the reset button *K* also carries the contact *B* to the right and prevents the blade *A* from reaching it. The position of the parts, when the reset button is pushed in, is

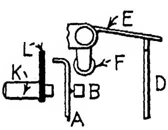


FIG. 124.

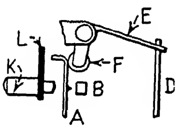


FIG. 125.

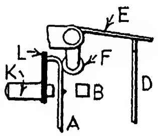


FIG. 126.

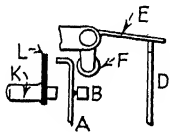


FIG. 127.

FIG. 124.—Essential parts of safety shut-down switch.
FIG. 125.—Same as Fig. 124 but with open contacts.
FIG. 126.—Position of parts of safety shut-down switch when reset button pressed down.
FIG. 127.—Same as Fig. 126 when reset button released.

shown in the diagram of Fig. 126. This last arrangement is designed to prevent anyone from wedging in the reset button and so operating the burner without the protection of the safety switch.

When the reset button *K* is released, the contact *B* moves to the left and makes contact with the blade *A* as shown in diagram of Fig. 127. The burner can now be started, but if flame or ignition failure (page 161) is repeated, the safety switch acts as before and a second safety shut-down results.

As soon as the relay or holding circuit is closed by the thermostat because heat is required, the current begins to flow through the heating element *F*. However, it requires about 90 seconds for the heater *H* to force the blade *D* far enough to the right to trip the safety shut-down switch. This allows sufficient time for the flame to be established if the burner and ignition system are functioning properly. An adjustment may be provided by which this time may be shortened if desired but it cannot be increased over 90 seconds.

Some other device must be provided to stop the flow of current through the heater *H* when the normal flame is established. This is usually accomplished by providing a by-pass or short circuit around the heater as soon as the temperature is sufficiently high in the smoke pipe or combustion chamber.

Pyrostat.—Such a device, called a *pyrostat or stack switch*, is shown in Fig. 128. This carries a thermostatic element (not shown in the figure) in the form of a long metal spiral arranged to turn a shaft as the temperature rises or falls. This spiral is inserted in the smoke pipe where it is exposed to the hot gases leaving the boiler. The shaft turns counterclockwise as the temperature rises and clockwise as it falls. The end of the shaft which extends into the pyrostat carries a fork (shown in Fig. 128) which engages the upper end of the contact blade. As the fork is rotated counterclockwise by the shaft, it forces the blade to the right, closing the contacts. These contacts are in the short circuit around the safety-switch heater, and when closed allow the heating current to by-pass the heater so that its action is stopped. The stack switch is adjusted so that a rise of about 50°F. in the flue-gas temperature will close the contacts. The fork is free to turn on the shaft but is held against a shoulder by a spring so that it is driven by friction. After the blade strikes the fixed contact, the fork slips and allows the shaft to turn farther as the temperature continues to increase.

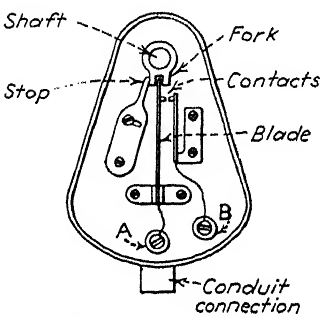


FIG. 128.—Pyrostat or stack switch.

If the flame should fail after ignition, the flue gases at once begin to cool and the fork, driven by its friction on the shaft, turns clockwise. When the temperature has dropped about 50°F. from its maximum, the contacts are opened, and the current again flows through the heater, causing a safety shut-down at the end of the timing period of the heater. The stop, shown at the left of the fork in Fig. 128, allows only a small movement of the fork, and further movement of the shaft causes slipping. By means of this "slipping" arrangement the pyrostat closes the circuit after a definite temperature rise and opens it after a definite

temperature drop, no matter what the actual temperature is at the beginning of these movements. This insures proper operation in response to a temperature *change* rather than to any definite temperature.

Another device, called a *protectostat,* which performs the same service as the pyrostat, is shown in Fig. 129. This is mounted with its "tube" inserted in the wall of the combustion chamber so that the radiant heat (page 245) from the flame can impinge on a thin metal diaphragm. Attached to the center of the diaphragm is a metal ribbon which passes over a roller to a tension spring. When the flame is established, its radiant heat raises the temperature of the diaphragm, causing it to expand. The edges of the diaphragm are rigidly clamped in the cast-iron frame

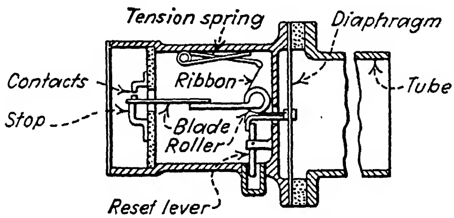


FIG. 129.—Protectostat.

so that the expansion forces it to buckle, the tension of the ribbon pulls the center toward the left, and the movement of the ribbon turns the roller clockwise. Attached to the roller is an arm which carries a *contact blade.* The motion of the roller raises the end of the blade and closes the contacts. With any further motion of the diaphragm the ribbon slips on the roller just as the fork slips on the shaft of the pyrostat or stack switch. If the flame fails, the diaphragm moves back toward the right and opens the contacts. When the blade has reached the stop, any further motion of the diaphragm causes slipping of the ribbon on the roller.

With some control circuits the burner will not start if the protectostat contacts are closed. It sometimes happens that rough handling or unusual vibrations will close the contacts when the diaphragm is cold. To remedy this a *reset lever* is provided. The lower end of this lever is covered by a cap which is screwed into the frame of the protectostat. If the cap is removed, the lower end of the lever can be pushed to the right. This will

pull the diaphragm to the left and slip the ribbon over the roller. When the lever is released, the diaphragm snaps back to the right, turning the roller counterclockwise and opening the contacts. It should be understood that the pyrostat and the protectostat are simply two different devices to perform the same operation. They are both connected electrically in exactly the same way, and either one may be used. The electrical connections of these devices are shown on pages 169–173.

General Types of Control System.—Broadly classified, temperature- and pressure-control systems belong to three general types, as regards the kind of motion given by the controlling device (thermostat, etc.) to the controlled equipment. Although there are in general only three types according to a "kind-of-movement" classification, it must be understood that in many heating, ventilating, and air-conditioning systems under automatic control there will be more than one and sometimes all three of these types of control in use in the same equipment. The three types of control with respect to kind of movement are: (1) Two-position control ("on-and-off" control); (2) floating control; and (3) modulating control. These types will be described somewhat in detail in the following paragraphs.

Two-position Control. Positive-acting Control.—Two-position control, positive-acting control, and "on-and-off" control are different names for the same type of control in the classification according to kind of motion used. The names "two-position" and "on-and-off" control, when used with respect to this type of control, are probably more descriptive than "positive-acting control." The first two names clearly indicate that always one of two possible limiting positions is maintained by the device. A typical example of a two-position-control device is a simple thermostat which starts and stops the oil burner of a heating system by the opening and closing of the electric circuit of a solenoid or similarly operated automatic switch. It should be noted that two-position control implies limit controls (page 145). The thermostat merely selects between its movements for starting and stopping the oil burner by the opening or closing of a switch, meaning that there are no intermediate positions or degrees of movement between the two extremes of operation. There are, however, types of two-position-control devices for which the designations "on" and

"off" are not suitably used, as, for example, in the case of a louvre damper (page 297) where it is not merely a matter of starting and stopping but a more continuous movement back and forth from the full-open to the full-closed positions or the reverse of this graduated movement.

Because of simplicity in principle and construction, two-position control devices are quite generally used. There are, however, quite definite disadvantages, at least under certain conditions. One of the disadvantages of special importance occurs in the use of two-position control for the regulation of a by-pass damper in connection with a heating coil. Such an application requires obviously the flow of all the air through the heater or the flow of all of the air around the heater. Consequently, the warm air discharged from such a system will vary so much in temperature that it would likely cause discomfort to the occupants of rooms in which the heat is controlled by this method. A better method of heat control is therefore desirable in the case that has just been mentioned. However, it should be noted that it is a common practice in connection with *pre*heating coils that are supplied with steam, to open the steam valve completely in order to accomplish the necessary tempering of the outside air. When the tempering is not required, the steam valve is completely closed. The two-position control is therefore very well suited to the usual practice in the use of preheating coils.

Floating Control.—In the preceding paragraph, reference was made to the desirability of having for some purposes of heat regulation a control device that does not necessarily operate on maximum and minimum positions. One way to accomplish this improvement is to use instead of a two-position system, a floating-control system which has in addition to the maximum- and minimum-limit controls intermediate electric-contact settings of the thermostat which permit stabilization of movement at corresponding intermediate values of temperature. The method of operation with *floating control* may be illustrated by the following room conditions when, for example, the temperature is to be held between 70° and 72°F. When, in this case, the room temperature drops to 70°F., the temperature-control device operates automatically to open a damper which changes the flow of at least part of the air; thus the air goes through the heating coil and at the same time reduces correspondingly the

area of opening of the damper through which the air is by-passed around the heating coil. The heated air thus distributed to the various rooms at the required temperature by the damper-actuating mechanism, will continue to open up the damper regulating the flow of air over the heating coil. At the same time it will continue to close the by-pass damper, until either or both have reached the limiting positions, or until one of a series of contacts in the thermostat is separated so as to break the electric circuit. As the temperature is now somewhere between 70° and 72°F., there will be no further operation of the damper mechanism; accordingly, there will be no further movement of the dampers until the temperature either drops to 70°F. again when it will still further open the dampers regulating the flow of air over the heating coil or until the temperature increases to 72°F., at which point the operation of the damper mechanism will be reversed. This kind of motion of the heat-control mechanism "point by point" is called "floating control." In connection with this name, it is interesting to note that the dampers on both the heating coil and on the by-pass coil are almost constantly in an unstable position and may therefore quite correctly be spoken of as "floating" from one position to the next.

Modulating Control.—Proportioning control is the significant name of a method of control which resembles floating control but is somewhat different in its operation. The technical name for this type of control by proportioning is *modulating control.* It is also sometimes called "automatic" control; these names being used to designate the kind of control in which a regulating valve or damper modulates or proportions a supply of air, steam, or water, according to changes of conditions at the controlling instrument. Modulating control brings about movement of the control elements of the system in proportion to the corresponding motion in the controlling device itself, by fractional variation. After fractional changes of position have occurred in the primary controlling device and have been translated into the terms of a new position of the valve or damper that is required to be moved, the modulating system stands by and awaits further change in the conditions at the controlling device. The extent of the movement for any one set of conditions is limited only by the limits of the controller and by the intensity of the change of conditions. In this type of control device, therefore, the valve

or damper that is being regulated is changed in position as often as there are changes of conditions at the controlling instrument. In this type of device, the change of position is always in direct proportion to the amount of change in the primary controlling instrument. Assuming that the thermostat, the primary controlling device, is to be set so as to cover the temperature range from 70° to 72°F., then, presumably, at 72°F., the damper controlling the flow of air to the heating coil will be completely closed, but if the temperature drops fractionally, for example, ¼°F., so that the temperature reading is 71.75, the modulating damper will bring about the opening of the damper controlling the flow of air over the heating coil ¼°F. or 12.5 per cent of its total movement. If again the drop in temperature had been ½°F., that is, down to 71.5°F., the damper controlling the flow of air to the heating coil would have opened 25 per cent of its total possible travel. The important point to remember, however, in connection with modulating control is that after each such change, the damper or dampers that are controlled will stand still and await the next movement of the primary controlling device which, in most cases, is the thermostat.

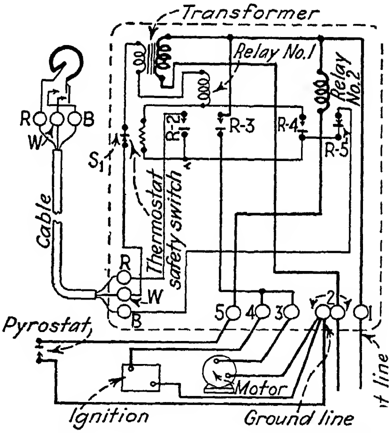


FIG. 130.—Control panel as assembled at factory.

Control Panels.—Most oil-burner control systems require complicated electrical connections in the various parts. To simplify installation work it is usual to assemble a transformer, thermal safety switch, one or more relays, etc., on a "control panel" which can be mounted on or near the oil burner. The wiring between the devices on the panel can be done in the factory leaving only the lines to distant devices to be installed in the field.

One such control panel with its connections is shown in Fig. 130. It provides for temperature control by a conventional room *thermostat*, combustion control by a *pyrostat* and *thermal safety switch*, and *constant electric ignition*.

The dotted line in the figure indicates the boundary of the control panel. All circuits shown inside this area are assembled in the factory and the exterior circuits are connected in the "field" to the proper binding posts. The power-supply lines are connected to binding posts 1 and 2 (the "hot" line (page 121) to binding post 1). One motor wire is connected to binding post 3, and one ignition wire to binding post 4, the return wires from both being connected to binding post 2. The three-wire cable from the room thermostat is connected to binding posts *R*, *W*, and *B*. There are two relays, each operating two switches. Number 1 relay is in the low-voltage thermostat circuit, but No. 2 relay takes full line voltage. When no current flows in No. 2 relay, the switch *R*-4 is open and *R*-5 is closed; when the relay circuit is closed, the switch *R*-4 is closed and *R*-5 is open.

When the thermostat cools, it closes first the white and then the blue contact. This completes the holding circuit of relay No. 1 which may be traced as follows: From the white contact of the thermostat, to binding post *W* on the thermostat, through the cable to binding post *W* on the control panel, to S_1, the switch element of the thermal safety switch, through the secondary winding of the transformer, through the No. 1 relay coil, through the heating element of the thermal safety switch, across to switch *R*-5, to binding post *B* on the panel, and back through the cable to binding post *B*, the blue contact, and the blades of the thermostat. The current in this circuit operates No. 1 relay and closes switches *R*-2 and *R*-3. The relay circuit provides the alternative path (for the holding current) through the red wire, instead of through switch *R*-5 and the blue wire.

Closing the switch *R*-3 closes the motor and ignition circuits as follows: From the "hot" line through binding post 1, up the right side and across to about the center of the top of the panel, down through *R*-3 to binding posts 4 and 3. From post 3 the circuit is through the motor, back to binding post 2 and the ground line, and from binding post 4 through the ignition system back to binding post 2 and the ground line.

This starts the burner and, if everything operates normally, the flame is established and the stack temperature rises and closes the pyrostat switch. Relay No. 2 holding circuit is now closed and may be traced from the "hot" line through post 1, through

the relay coil, post 5, and through the closed pyrostat switch to post 2 and the ground line. Relay No. 2 opens *R*-5 breaking the blue line which is not needed as long as *R*-2 to the red line is closed. At the same time *R*-4 is closed, which by-passes the heating element of the thermal safety switch as follows: from the lower end of relay coil No 1 through *R*-4, up through *R*-2, to binding post *R*. Since the resistance of this line is much less than that of the heating element, practically no current will flow through the latter, and it will cool off.

If the ignition fails, the stack temperature will not rise, the pyrostat switch will not close, and, at the end of its timing period, the thermal safety switch will open switch S_1. This will drop out relay No. 1 and shut down the burner. If the flame fails after normal operation is established, the cooling of the flue gases opens the pyrostat switch, which drops out relay No. 2 and sends all the relay No. 1 holding current through the safety switch heater, causing a safety shut-down.

Switch *R*-5 is provided to prevent a restart (after any stop) until the stack gases have cooled. For example, in the event of a power failure, both relays will fall out and everything stops. If power is restored before the combustion-chamber refractory lining has cooled, the firebox may be filled with unburned fuel which may be ignited by the hot refractory lining and cause an explosion. However, the pyrostat switch will not open until the refractory lining has cooled; and if power is restored, relay No. 2 will open *R*-5. But relay No. 1 once having opened cannot close unless the blue circuit (through *R*-5) is closed. Therefore the burner cannot start unless the pyrostat switch is open. After such a power failure, if power is restored, the control system will be set back to its normal position, after the pyrostat switch opens, and start the burner again, provided the thermostat still demands heat.

In Fig. 131 another example of a control panel is shown. In this case the pyrostat switch is in the low-voltage circuit and also the ignition is cut off as soon as the pyrostat switch closes. Switches *R*-4, *R*-5, *R*-6, and *R*-8 are normally open but are all closed when relay No. 1 pulls in. Switches *R*-7 and *R*-3 are normally closed but are opened when relay No. 2 pulls in, while *R*-2 (also operated by relay No. 2) is normally open and is closed when the relay operates.

When the thermostat demands heat, the holding current flows from the white contact, through post *W*, through S_1 of the thermal safety switch, the transformer secondary, relay coil No. 1, the terminal of switch *R*-2 (but not through the switch which is open), through the safety-switch heater, up across the top of the panel, down through *R*-3 and back through post *B* to the thermostat. This pulls in relay No. 1.

Closing *R*-4 provides the alternative holding circuit through the red line. The *motor circuit* is completed from post 1, through *R*-8, down through *R*-6, to post 3 through the motor, and back to

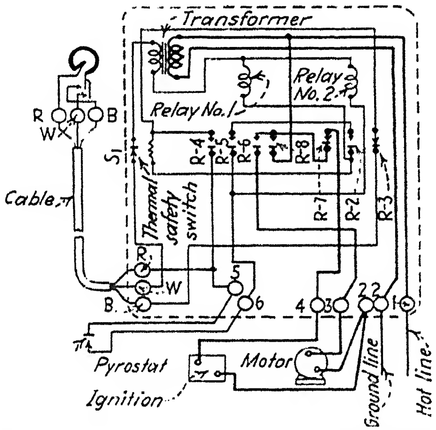


FIG. 131.—Control panel with pyrostat switch.

post 2. At the same time the ignition current flows through *R*-8, *R*-7 (which is closed, relay No. 2 being out), post 4, the ignition system, and post 2.

When the rise in stack temperature closes the pyrostat switch, the circuit of relay No. 2 is completed from post *W*, through S_1 switch, the secondary of the transformer, relay coil No. 2, post 6, the pyrostat switch, post 5, post *R*, the thermostat, and back to post *W*. This opens *R*-7, cutting off the ignition, and *R*-3, breaking the blue line. It also closes *R*-2, so that the relay No. 1 current can flow through *R*-2, *R*-5, post 6, the pyrostat switch, post 5, post *R*, etc., instead of through the safety-switch heater.

If, once relay No. 2 is closed, the pyrostat switch opens, relay No. 2 does not fall out. Its holding current, instead of flowing

through the pyrostat switch, flows up through R-5, down through R-2, through the safety-switch heater, R-4, post 5, etc. The holding current from relay No. 1 joins that from relay No. 2 at the terminal of R-2 and must now flow through the heater. This double current causes the safety switch to open S_1 in about half its normal time, giving a quick safety shut-down in case of flame failure.

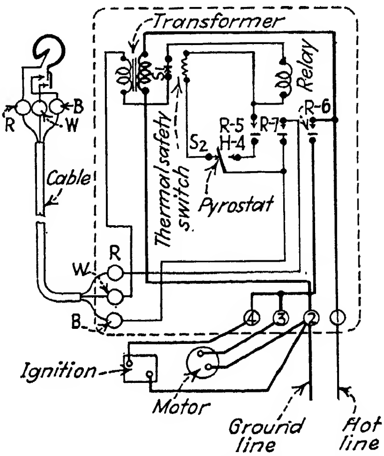


FIG. 132.—Stack-mounted panel for constant ignition.

The control panels of Figs. 130 and 131 are only two examples of many different arrangements used for oil-burner control. Combinations can be, and are, made up to meet the ideas of different burner designers. It is a good plan to trace the circuits on the illustrations until they are thoroughly understood. After such practice one should be able to follow the diagrams and

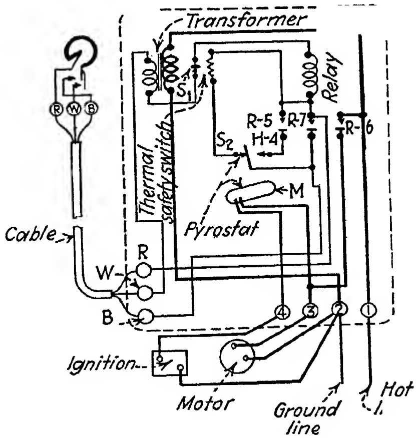


FIG. 133.—Stack-mounted panel for ignition cut-off.

instructions furnished by the manufacturer for any special arrangements of oil-burner controls.

To meet a demand for a more compact control the so-called "stack-mounted" panels were developed. In these controls the pyrostat switch is mounted on the panel, the pyrostat thermostatic element extends through the back of the panel, and the whole device is mounted on the smoke pipe. Two of these are illustrated in Figs. 132 and 133, the former arranged for constant ignition and the latter for ignition cut off. In both cases the pyrostat switch has two contacts, one (S_2) is closed when the stack is cold, and the other (H-4) is closed when the stack is hot. The switch is arranged to overlap the contacts. That is, as the temperature rises, *H-4 is closed before the switch S_2 is opened.*

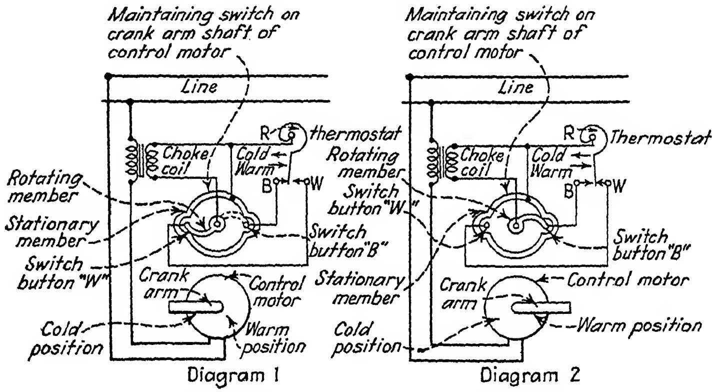


FIG. 134.—"Series 20" thermostatic control.

The mercury switch shown in Fig. 133 is attached to, and moves with the pyrostat switch. In both cases, when the relay operates, all three switches, R-5, R-7, and R-6, are closed.

"Series 20" Control.—The *motorized valve* mentioned on page 157 requires a different type of control known as "Series 20." A "Series 20" thermostat has only one blade which has a blue contact on one side and a white contact on the other (see Fig. 134). A small control motor is used instead of relays, and this motor turns a set of crank arms to one position when the thermostat demands heat and through one-half turn from this position to another position when no more heat is needed.

Referring to Fig. 134, the curved arm marked "Rotating Member" is one of these arms and is on the same shaft as that marked "Crank Arm" in the circle representing the control

motor. (These two arms are shown one above the other to avoid complications in the diagram.) In diagram 1 of Fig. 134 the thermostat is cold and so the blade has closed the blue contact; the crank arm has opened the valve in the riser, allowing water to circulate to the radiators. The outer end of the rotating arm is in contact with "Switch Button *W*." The motor is connected to the power line through the primary winding of the choke-coil (page 122) transformer. Since the secondary circuit is open, no current will flow to the motor.

Suppose now the room temperature rises so that the thermostat blade closes the white contact as in diagram 2. This establishes a circuit as follows: (diagram 1) from the thermostat white contact to the switch button *W*, through the rotating arm, to the choke-coil secondary, to the red post on the thermostat, through the blade to the white contact. This allows current to flow through the primary winding and operates the motor which turns the rotating member and the crank arm counterclockwise. Before the rotating member leaves the switch button *W*, it makes contact with the stationary member. This provides an alternative circuit through the choke-coil secondary, thus continuing the operation of the motor after the rotating member has moved off the switch button *W*.

When the rotating member reaches the position shown in diagram 2, it breaks contact with the stationary member, opening the secondary circuit and stopping the motor. The crank arm is now in the "Warm" position (diagram 2) and the circulating valve is closed. The rotating member is in contact with switch button *B* ready to start the motor again as soon as the thermostat closes its blue contact.

The *motorized valve* referred to on page 174 is a butterfly valve assembled with a "series 20" control motor so that the valve is opened and closed by the crank arm. Obviously such a control motor could be used to open and close dampers, operate a switch to control an oil-burner motor, or perform any other duty requiring a two-position control.

There is a fundamental difference between the so-called "series 10" control explained on page 170, and the "series 20" control, which if kept in mind, will often help in tracing troubles. In "series 10" control the blue and the white circuits are closed for starting, the red and white circuits are closed to continue normal

operation, and the white circuit is opened to stop. In the "series 20" control the blue and the red circuits are closed for starting, and the white and the red circuits are closed to stop. Once operation is started, it will continue until the white and the red circuits are closed, no matter what happens to the blue circuit.

Forced Hot-water Heating Systems.—It is becoming increasingly common to install a motor-driven centrifugal pump, or "circulator," in hot-water heating systems. This provides positive circulation through the boiler, piping, and radiators, and is much quicker in response than a gravity circulation system. The pump motor is controlled by the room thermostat which may be either "series 10" or "series 20." Where the motor takes no more than 10 amperes, a line-voltage room thermostat is sometimes used.

A flapper valve, held shut by a weight, is provided to prevent gravity circulation while the pump is stopped. When the pump is running, it builds up pressure enough to open the valve against the weight.

The oil burner is controlled by an aquastat in the boiler. This maintains a supply of hot water in the boiler ready to provide heat promptly when the room thermostat demands heat.

Furnace-fan Control. Furnacestat.—Many warm-air heating systems include a ventilating fan for the "forced" distribution of air through the various rooms of a building. In order to avoid the distribution of cold air into the rooms in such a way as to produce an uncomfortably cold draft, it is usually necessary to provide some kind of control device to delay the circulation of air by the ventilating fan until the air has been sufficiently warmed by the furnace to prevent the discharge of cold air into the rooms. Such a device is commonly called a "furnacestat."

Humidity Control.—Many oil-burner heating installations include apparatus for regulating the amount of moisture in the air discharged into the rooms for heating. As a rule, such humidifying apparatus is controlled by an automatic device which is sensitive to changes in humidity, and especially to relative humidity (page 355).

Auxiliary Controls.—Many auxiliary-control devices are available, each designed to improve some phase of the burner operation. Probably the oldest of these is the "clock" thermostat which automatically lowers and raises the thermostat setting at

certain set times. Thus the temperature is reduced during the night or when the building is unoccupied, and some saving in fuel may result (page 283). The same result can be attained by manually setting the thermostat, but this requires personal attention.

With intermittent control cold currents of air are likely to be set up during the latter part of the "off" periods of operation. This effect is known as "cold seventy" (page 150) since a sensation of cold is felt even though the thermostat starts the burner as soon as the temperature drops to or below 70°F. Several arrangements are available to start the burner when the temperature of the radiators or of the boiler water drops below a certain point, even when the room thermostat demands no more heat. Such devices are known as "low-limit" controls. Another class of controls, designed to eliminate "cold seventy," starts the burner at *regular time intervals*.

If domestic hot water is to be heated during the entire year by the heating-system burner, some method of control is required to maintain the desired water temperature without heating the building during warm weather. Such devices called "summer-winter" controls are explained on page 156.

Classifications of Compensated Control Circuits.—There are two principal classifications of compensated automatic-control circuits. This classification is based on the type of operation that leads to the final control result. These two classifications are: (1) Two-position or "on-and-off" control; and (2) modulating control. These two types of control were explained in considerable detail with respect to all types of control apparatus on page 166.

Two-position Compensated Automatic Control.—In all types of control apparatus that have been explained, the two-position type is simpler in construction and operation than the modulating type, and, for that reason, the two-position type will be explained first, with reference especially to Figs. 135 and 136. Figure 135 shows the internal wiring and Fig. 136 the external wiring for a two-position control device that consists of one compensator and one controller; the latter is used to move an electromagnetically operated relay. The *compensator* shown in the figures is constructed so that it will respond to changes in temperature, in this case by means of a bellows type of thermostat (page 147),

and will operate so as to determine the control point of a second device. On the other hand, the *controller* in such a regulation

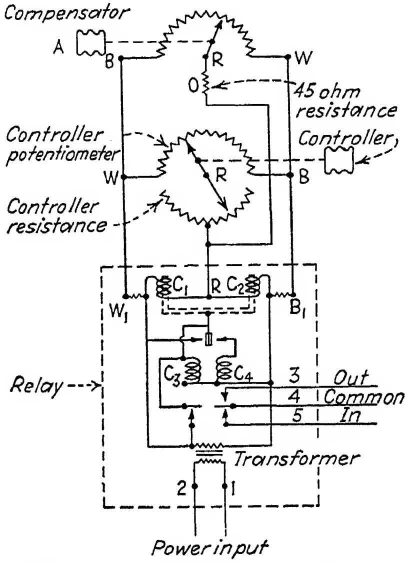


Fig. 135.—Internal wiring of two-position compensated control with one compensator and one controller.

system is a device which measures temperature, humidity, or pressure, and produces changes in the source-regulating device so as to maintain a fixed or a desired condition. The controller illustrated in outline in Figs. 135 and 136 operates a relay which may be used for starting or stopping an air compressor for opening or closing a two-position solenoid valve, a two-position electric-motor operating valve, or some other "on-and-off" device. Any change in the position of the temperature-actuated bellows, which is the compensator device in this case, tends to unbalance the electric current flowing through the two coils C_1 and C_2 (Fig. 135) of the

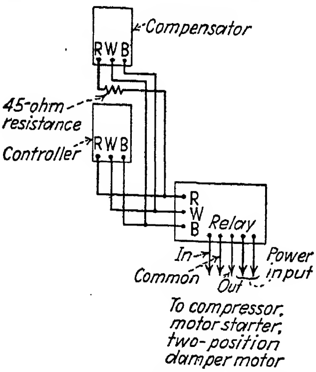


Fig. 136.—External wiring of two-position control with one compensator and one controller.

relay. Now, if this change in position of the bellows-actuated compensator is of considerable magnitude, it may have the effect of reversing the position of the contacts operated by the solenoid coils C_1 and C_2. In that case, the relay device will operate so as to change the conditions of heat supply to such an extent that it will be set to the opposite position. In this connection, it should be kept in mind, however, that the *compensator device is only a measuring instrument* and serves only as such so that it is not affected by the operation of the relay. On the other hand, the controller is affected by the changes brought about by the relay device, and therefore a new control point is set up in the controller (in order to maintain a balanced system) for each fractional change in the position of the compensator.*

A relatively small change in the position of the controller is only needed to bring about the reversal of the position of the relay. If a suitably designed relay is used in such a control device, a change of only about 5 per cent of the total travel of the controller is necessary in order to cause reversal of the relay. In other words, the operating differential of the controller is about 5 per cent of its total differential.†

The insulation on the wires used in the various parts of the system is colored white, blue, and red, the color depending on the kind of service to be performed. In this and similar types of regulating devices for temperature, relative humidity (page 355), or pressure control, red is the color for the common or center contact wire, the blue for the low side, and the white wiring for the high side. For example, Fig. 135 shows the blue and white contacts of both the compensator and the controller in the *reverse position* with respect to each other, which is the position of the

*For a more detailed description, consult instruction bulletins of Minneapolis—Honeywell Regulator Company, Minneapolis, Minnesota.

† *Total differential* of a controller is the change in the position of the controller contact from one extreme of the potentiometer coil (page 184) to the other extreme; for example, if a thermostat has a total differential corresponding to an arc of 10° in circular measurement, a change of 10°F. will be required to move the temperature-actuated contact from one end of the potentiometer coil to the other end.

Operating differential is similarly a change in the position of the controller contact from one position to another on its potentiometer coil which will *not* be sufficiently large to operate a relay designed to move an electric motor or a solenoid-actuated valve from one position to another. Since a compensator does not control, it does not have an operating differential.

blue and the white wiring when, for example, a *rise* in the temperature measured by the compensator calls into action the control device in such a way as to *raise* the control point of the controlled condition.

If, however, the same control point is to be *decreased* at the same time that the measured condition, as, for example, the temperature is to be *increased*, then the wiring would be connected "color to color." Thus, if, for example, it is desired to raise the dry-bulb control point (page 188) inside a building in some proportion (arithmetic or otherwise) to correspond to increases in outdoor temperatures, the compensator and the controller terminals should be wired in the reversed position, that is, blue to white and white to blue; but if the relative humidity in a room is being measured by a suitable compensator, and the condition is to be established that will cause the reduction of the dry-bulb temperature inside the building as the relative humidity inside the building increases, then the compensator and the controller would be wired "color to color," that is, the white wiring would be connected to white wiring, and blue wiring to blue wiring.

The settings of the compensator and controller for the preceding typical examples are the following:

Example 1.—*Compensated dry-bulb control:* Outdoor compensator set for a range of 75° to 100°F. and indoor controller set for the range from 75° to 85°F.

Example 2.—*Effective temperature control:* Relative humidity compensator set for a range of 30 to 60 per cent and temperature controller set for a range of 75.5° to 78.5°F. It will be noted in Fig. 135 that in the wiring of the compensator there is an ohmic-resistance wire which is a part of the red contact wire. It is used in order that the controller may have complete control over the relay with respect, especially, to "on-and-off" positions, even when the compensator is at either extreme end of its range.

There are two ohmic resistances (page 122) at the blue and white terminals of the relay, which are marked respectively B_1 and W_1. They are only protective resistances and have no effect whatever on the operation of the control circuits. The relay shown in the figure provides for the single-pole, double-throw action, either side or both sides of which may be used.

There is also ohmic-resistance wiring in the controller circuit, as shown in Fig. 135. The upper part is that of the potenti-

ometer (page 184), and the lower is an ohmic resistance which is added for the purpose of equalizing the differential operation (page 179) of the control circuit throughout the range of the controller. This resistance is necessary because the controller would otherwise become more sensitive as it approaches its extreme positions; and, consequently, the operating differential would become shorter at these extreme positions.

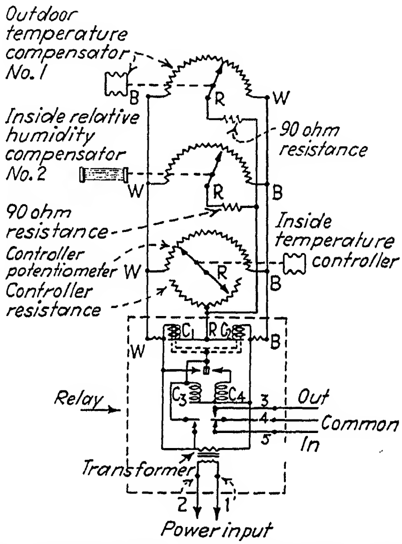


FIG. 137.—Outside wiring diagram of two compensators and one controller.

Figure 136 shows in bare diagrammatic form the external wire connections of the automatic-control circuit which is shown in considerable detail with respect to the inside wiring in Fig. 135.

Two-position Automatic Compensated Control with Two Compensators and One Controller.—A typical wiring diagram of two-position compensated automatic control which has two compensators and one controller to operate a relay, is shown in Fig. 137. The operation of this system is almost exactly the same as that of the one just described that has only one compensator, except that the *average* effect of the two compensators determines the control point of the controller. Like the control circuit shown in Fig. 135, this one is also suited for starting and stopping

air compressors, and opening and closing two-position motor-operated or solenoid-operated valves, or other on-and-off devices.

Since the principles involved in the operation of the control circuits of Fig. 137 are so nearly the same as those of Fig. 135, it is probably only necessary here to state typical applications. For a specific example, assume that compensated *effective temperature control* is to be provided in a building for the condition when the dry-bulb temperature outside the building is used to regulate the effective temperature-control point (page 190) inside

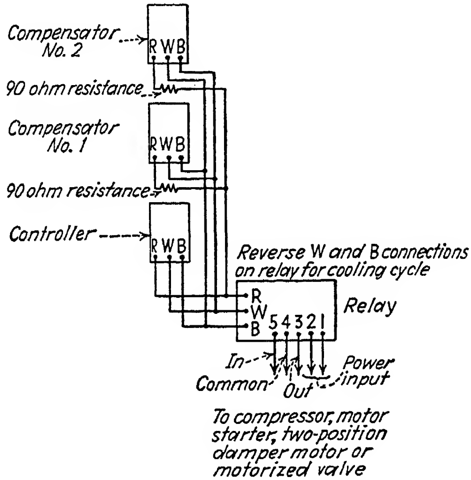


FIG. 138.—Inside wiring diagram of two compensators and one controller.

the building; and that in order to accomplish this result, the inside relative humidity is measured by a suitable device which determines the dry-bulb-temperature-control point inside the building. The typical data might be listed as follows for these conditions: (1) outdoor temperature by compensator device 75° to 100°F.; (2) indoor-relative-humidity compensator, 30 to 60 per cent; (3) indoor-temperature controller, 73° to 82°F.

As the wiring of the circuit in Fig. 137 is arranged, the relay terminal for the blue wire indicates the *low* point for each condition that is controlled; and the terminal for the white wire indicates the *high* point. Consequently, the terminals as shown will produce a low temperature-control point inside the building when the outside temperature is low and the inside relative

humidity is high; or, on the other hand, a high inside-temperature-control point when the outdoor temperature is high and the inside relative humidity is low. If both the outdoor temperature and the inside relative humidity are either low or high, an intermediate inside-temperature-control point will be produced. The external wiring connections for a control system of which Fig. 137 shows the inside wiring, is illustrated in Fig. 138, which is intended, as in the case of Fig. 137, for the use of two compensators and one controller.

Modulating Automatic Control.—It has already been explained that the principal difference between two-position compensated control and modulating compensating control is that the former provides only for on-and-off operation, while a modulating system of control accomplishes the same limiting results with the additional advantage that the final operating mechanism produces the modulating movement of an electric motor-operated valve or other similarly controlled apparatus. The modulating system of control always requires the practical application of a so-called "modutrol" or proportioning motor. Since an understanding of this compensated modulating system will depend on a good understanding of the operation of the so-called "standard" modulating system, the standard system will first be explained.

Standard Modulating System.—The operation of a modutrol motor by a temperature-actuating device which, in this case, is a bellows type of thermostat, is shown in Fig. 139. The effect of temperature changes at the thermostat A produces corresponding changes in the position of the electric contact N on the potentiometer controller. When these changes are either "fractional" or complete, they have the effect of altering appreciably the electrical balance of the control system, so that more power is given to one or the other of the relay coils C_1 or C_2. Such a shift of power to the relay coil C_1 causes the movement of the relay yoke Y; so that it will move toward the left-hand side to such an extent that the electrical circuit is closed to the electric motor M_1, which then, in turn, moves the contact S on the balancing potentiometer in the direction which will produce the corresponding change of current in the other relay coil C_2. When the power supplied to this other relay coil equals the power delivered to the first relay coil C_1, the relay yoke Y will return to its neutral position, thus stopping the motor M_1. On the

other hand, a "fractional" movement of the electric contact N on the potentiometer of the controller in the opposite direction from that just described will give more power to the relay coil

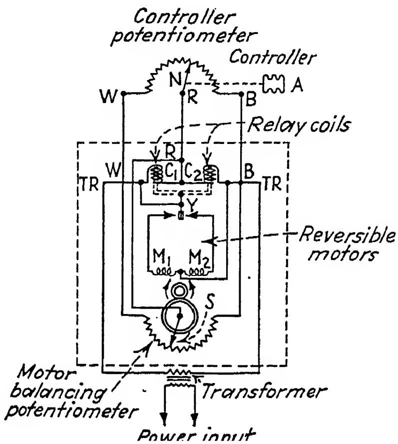


Fig. 139.—Modutrol motor actuated by thermostat.

C_2 and will consequently move the relay yoke Y toward the right-hand side, and thus complete the electrical circuit of the other motor M_2. When this motor is set in motion, it will move the electric contact of the balancing potentiometer in the opposite direction from its previous movement to such a point where the power in each of the relay coils is the same, and, in that case, the relay yoke Y will again return to its neutral position and the motor M_2 will, of course, be stopped.

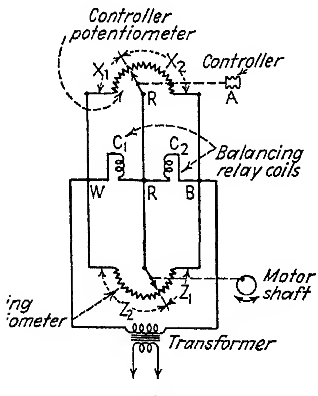


Fig. 140.—Balancing control portion of modutrol motor.

As the device illustrated diagrammatically in Fig. 139 is constructed, it is not so simple as it is shown in the diagram, for the reason that as actually made, it includes protective resistances, limit switches, and booster coils. These various other parts are provided to avoid (1)

electric short circuits, (2) limitations of the travel of the electric motors M_1 and M_2, and (3) objectionable arcing at the contact points. These additional protective parts, however, have no relation whatever to the operation of the balancing system of this control device.

In order to explain further the system of compensated modulating control, the diagram shown in Fig. 140 has been prepared in which the operating mechanism shown in Fig. 139 has been omitted, and only the part for balancing control is shown. When the compensated modulating control system is in balance, it is obvious that the relay coils C_1 and C_2 will each receive the same amount of electric power; and since electric current will always seek the path of least resistance, the electric power supplied to the relay coil C_1 will be delivered through the resistance Z_1 and the relay coil C_2 will receive its power through the resistance X_1, as shown diagrammatically in Fig. 140. In order to establish this set of conditions, it is necessary that, in the position shown, the resistance X_1 be equal to the resistance Z_1 if, the resistances C_1 and C_2 are exactly the same, and, in that event, also X_2 will be equal to the resistance Z_2. From these relations it will be noted that any change in the position of the controller contact N (Fig. 139) will change the values of the resistances X_1 and X_2; and consequently when the resistance X_1 is reduced, the power supplied to the relay coil C_2 is increased, and conversely, when the resistance X_1 is increased, there will be a reduction in the power supplied to the relay coil C_2.

As shown in Fig. 139, this unbalanced condition causes the relay yoke Y to complete the contact to one of the reversible motors M_1 or M_2, which will move the balancing potentiometer contact N in the direction which will cause Z_1 to equal X_2. When these conditions are obtained, the two relay coils will receive the same amount of power, and consequently the motor that has been operating will be stopped. If the contact point N of the controller potentiometer bears toward the right-hand side instead of being inclined toward the left-hand side, as shown in Fig. 140. the resistance X_2 will be less than the resistance X_1; then, if the system is in balance, Z_2 will be less than Z_1. In that case, the relay coil C_1 will receive its power supply through the resistance X_2, and the other coil C_2 will receive power through the resistance

Compensated Modulating Control with Operating Differential. A rheostat can be used to increase the resistance of a portion of a circuit including a balancing potentiometer to increase the sensitivity of the controller potentiometer. Figure 141 shows diagrammatically the method of obtaining an "operating differential" (page 179) as a part of a total differential of the controller. This is accomplished by the use of the rheostat to increase the sensitivity of the controller potentiometer. The movement of the controller through its operating differential X_4 can be balanced by a movement of the contact point of the motor-balancing potentiometer through its total differential X_3.

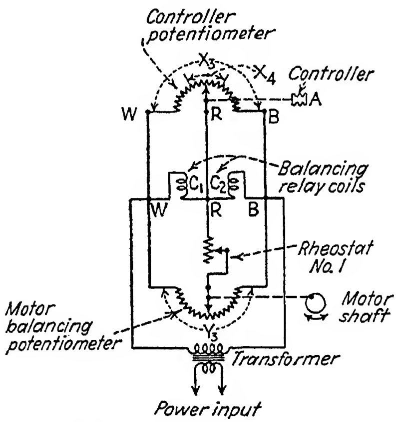


Fig. 141.—Compensating modulating control with operating differential.

As represented in Fig. 141, X_3 is the total differential of the controller. Changes in the resistance value of the rheostat provide a means of varying the ratio of the operating differential X_4 of the controller to its total differential. According to the representation in the figure, the operating differential X_4 of the controller will always be in the center of the total differential X_3. In Fig. 142, a compensator is shown in the top of the diagram. This has been added for the reason that it can be used to control the position of the operating differential X_4 in relation to the total differential X_3.

A slightly different arrangement is shown in Fig. 142, where a *compensator* potentiometer is shown at the top of the diagram. This is to be used for adjusting the position of the operating

differential X_4 of the controller in relation to its differential X_3. The figure shows also a rheostat marked No. 2, which is in the line of wiring leading to the compensator contact of the *compensator* potentiometer Z_1. This rheostat is intended to provide a means of varying the effect of the compensator on the controller. If this No. 2 rheostat is not included in the circuit then the controller would not always have full control over the modutrol motor. Since the control point of the controller is at the middle of the operating differential, X_4, it is necessary that the No. 2

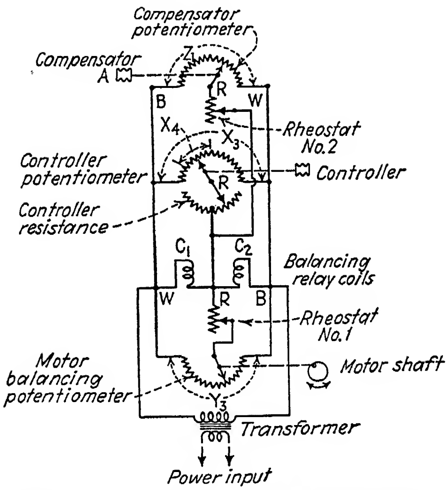


FIG. 142.—Modulating control with operating differential and compensator potentiometer.

rheostat should be so set that one limiting position of X_4 will coincide with one limiting position of X_3, whenever the compensator contact is at one of the extreme positions of the *compensator* potentiometer Z_1. Thus for example, if the compensator contact is at its extreme position on the right-hand side of Z_1, then the left-hand limiting position of X_4 must coincide with the left-hand limiting position of X_3. It must be kept in mind, therefore, in setting the controller that allowance must be made at each of its ends for one-half of the operating differential in order that the desired control point may be reached at each limiting position of the controller. However, since the compensator is only a *measuring* device and does not have any influence as a con-

trol device, it may be set in its extreme positions exactly according to a required schedule.

There is still another addition indicated in Fig. 142 that is not shown in Fig. 141. This is the "controller resistance," which is shown in the diagram just below the *controller* potentiometer. This resistance is used to equalize the effect of the operating differential X_4 throughout the total range of the total differential X_3. It is necessary to use this resistance because the controller would otherwise become more sensitive than it should be in the positions near the right-hand and left-hand limits, and, consequently, the operating differential X_4 would become shorter at these extreme positions. All protective resistances may be omitted from the compensated-modulating-control circuits because the two rheostats in Fig. 142 marked No. 1 and No. 2, and also the controller resistance, provide such protection.

In the application of compensators when the control condition of air, water, or any other fluid is intended to *increase* as the measured condition of the same fluid or of a different fluid *increases*, the compensator and the controller are connected by wiring as shown in Fig. 142, with the blue and white contacts on the two instruments reversed in relation to each other. If, however, the control condition of air, water, or any other fluid is to *decrease* as the measured condition of the same fluid or some other fluid increases, then the compensator and controller should be connected by wiring with blue joining blue and white joining white. In other words, in this latter case, the wiring would be "color to color." A typical example of the use of a compensator and controller for this type of service is the case where it is desired to raise the control point corresponding to the inside dry-bulb temperature as the outdoor temperature increases. In the application of the control device shown in Fig. 142 this would be a case where the terminals of both the compensator and the controller would be connected together so that blue wiring would be joined to white wiring; this being what is often called "reverse" wiring. On the other hand, a set of conditions like the following would require the opposite type of connections of the wiring which would therefore be color to color. In the case referred to, the relative humidity in a room is measured by a compensator of a suitable type and in order to accomplish the desired control, it is necessary to reduce the dry-bulb indoor

temperature in proportion as the relative humidity in the room increases.

Practical Example of Compensated Dry-bulb-temperature Control.—In accepted standard practice with outdoor temperatures between 75° and 100°F., the indoor-temperature-control point would have an acceptable range from 75° to 85°F. In this case, the compensated dry-bulb-temperature control is accomplished by the use of an outdoor-temperature compensator, and an inside-return-air-temperature controller (or room thermostat), which in turn operates the conditioning equipment. If an operating differential of 4°F. is desired, then obviously the controller setting should be 2°F. longer each way than the highest and lowest desired control points, and therefore the controller setting should be between 73° and 87°F.

Practical Example of Effective Temperature Control.—Relative humidity in a room determines the inside dry-bulb temperature, and consequently an instrument which measures the inside relative humidity determines automatically the control point of the inside dry-bulb temperature according to a schedule somewhat as follows:

Inside Relative Humidity, Per Cent	Inside-temperature-control Point, °F.
30	78.5
35	78.0
40	77.5
45	77.0
50	76.5
55	76.0
60	75.5

The tabulated schedule given above provides for a *fixed effective temperature* (page 180) of 71°F. Any other effective temperature within the comfort zone may be selected for summer or winter. Effective temperature control is accomplished by the use of an inside-relative-humidity compensator and an inside-return-air-temperature controller (or room thermostat), which in turn operates the conditioning equipment. In the practical case to be considered, the relative-humidity compensator provides for a variation between 30 and 60 per cent, and with the temperature controller it is desired to vary the indoor temperature

by amounts as shown in the tabulation from 75.5° to 78.5°F. If a 3°F.-operating differential is chosen, then the controller setting should be 1.5°F. longer each way than the highest and lowest desired control points (75.5 and 78.5). The controller setting would therefore be 74°F. for the low point and 80°F. for the high point.

The manufacturers of the type of concentrator or controller shown in Fig. 142 arrange the wiring so that the low-limit side is colored blue, and the high side is white. This method of marking is the same for temperature, relative humidity, or pressure controllers. The contact point on the red-colored wiring is always the common or center wiring.

When motorized valves are used, contact between the red and blue wiring opens the valve; and similarly, a contact between the red and white wiring closes the valve.

Modulating Motor-operated Valves with Compensators and Controller.—A typical wiring layout of two compensators (No. 1 and No. 2) and one controller operating a modulating motor is shown in Fig. 143. In its operation, this device is exactly the same as when only one compensator is used, except that the *average* effect of the use of the two compensators is to determine the control point of the controller.

Practical Example of Compensated Effective Temperature Control.—If it is desired to provide compensated *effective* temperature control, the usual procedure is to provide a suitable apparatus to measure the outdoor dry-bulb temperature and with this as a starting point to determine the inside *effective* temperature-control point, the inside relative humidity is then measured and this serves to determine the inside dry-bulb-temperature-control point.

When the outdoor dry-bulb temperature is measured, as already stated, the inside effective temperature-control point is determined automatically. The inside relative humidity is then measured, and similarly, the inside dry-bulb-temperature-control point is automatically determined. Both of these determinations are made according to a predetermined schedule (page 191). After the effective temperature-control point has been established, the inside relative humidity is measured and is used to determine automatically the inside dry-bulb temperature from the data in the preceding table. Compensated

effective temperature control is accomplished by the use of an outdoor-temperature compensator, an inside-relative-humidity compensator, and a return-air temperature controller (or room thermostat), which in turn operates the regulating equipment.

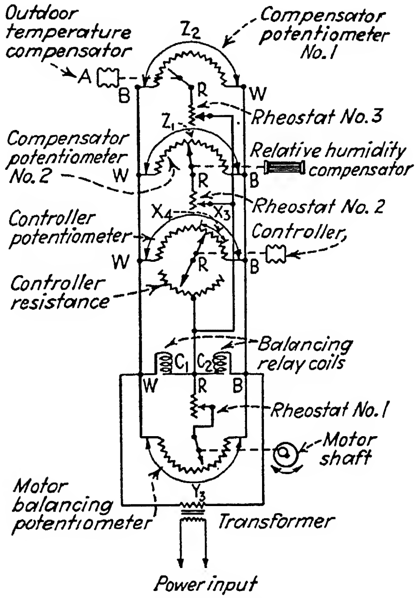


FIG. 143.—Modulating motor-operated valves.

The relation between the outside temperature and the inside effective temperature-control point is shown in Table X and is obtained from data furnished by a leading manufacturer of such equipment:

TABLE X.—EFFECTIVE INSIDE TEMPERATURES

Outdoor Temperature, °F.	Inside Effective Temperature-control Point,
75	69
80	70
85	71
90	72
95	73
100	74

In the practical problem now being considered, the outdoor-temperature compensator has the limits that are given in the left-hand column of Table X, and it is desired to vary the indoor temperature from 73° to 82°F. If there is an operating differential of 4°F. in this case, then the controller setting should be longer each way than the highest and lowest desired control points. The setting of the controller should therefore be between the limits of 71° and 84°F.

As the wiring is arranged in Fig. 143, there is an inside-temperature-control point when the outdoor temperature is low and the

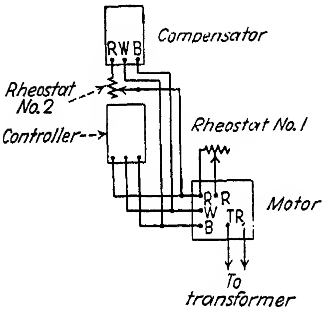


FIG. 144.—External wiring for modulating motor-operated valves with one compensator and one controller.

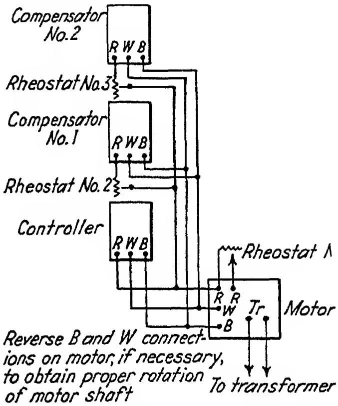


FIG. 145.—External wiring for motor-operated valves with two compensators and one controller.

inside relative humidity is high. Similarly, an inside-temperature-control point is reached, if the outdoor temperature is high and the inside relative humidity is low. Also, if the outdoor temperature and the inside relative humidity are both low or are both high, there will be an intermediate inside-temperature-control point.

As in the cases of other similar diagrams, Figs. 142 and 143 show the interior wiring of the compensators and the controller, while Fig. 144 shows the external wiring connections of a system corresponding to Fig. 142 which has one compensator and one controller. Figure 145 shows the external wiring corresponding to a system like Fig. 143, where there are two compensators and one controller.

Calculation of Ratio of Operating Differential to Total Differential.—In the case of the application in regulating equipment similar to the diagrams in Figs. 142 and 144 in which one compensator and one controller are used, the relation between operating differential and total differential of the controller must usually be calculated in order to determine the effective variable resistances to be used in rheostats. If the same example of compensated dry-bulb control is used in which it is desired to vary the control point of the "inside" controller from 75° to 85°F. and the operating differential is to be 4°F., then the *total* differential is $(85 + 2) - (75 - 2) = 14$°F.

The ratio of the operating differential to the total differential is then $4 \div 14$, or 0.29.

Compensated Relative-humidity Control to Prevent Frosting. With the use of suitable humidity-control devices, it is possible to regulate by means of the determinations of outdoor temperature and inside relative humidity the *frosting on windows.* The reason for this is that the outdoor temperature determines the amount of inside relative humidity in order to prevent the freezing of precipitated moisture on windows for *single-pane* windows. Table XI gives the limiting value of humidity in order to prevent frosting on windows.

Table XI.—Humidity to Prevent Frosting

Outdoor Temperature, °F.	Inside Relative-humidity-control Point, Per Cent
40	45
30	35
20	25
10	20
0	15
10 below zero	12

The equipment needed for compensated relative-humidity control consists of an outside compensator and an inside-relative-humidity controller (page 189) which in turn operates the mechanism used for adding moisture, if needed.

Compensated Delivered-air-temperature-control Devices.—By the measurement of the outside air temperature, it is possible to determine and control by automatic means the delivered- or supply-air temperature from Table XII.

TABLE XII.—TEMPERATURES OF AIR SUPPLY

Outdoor Temperature, °F.	Delivered-air-temperature-control Point, °F.
0	105
10	100
20	95
30	90
40	85
50	80
60	75
70	70

Compensated delivered-air temperature is controlled as indicated in Table XII by the use of either an outdoor- or an indoor-temperature compensator and a delivered-air-temperature controller which in turn operates the necessary air-conditioning equipment.

Compensated Hot-water-temperature-control Devices.—The temperature-control point of hot water for a heating system or for industrial uses can be controlled by a compensated control device measuring the outside temperature for the reason that the measurement of his temperature will serve for the automatic hot-water control according to Table XIII.

TABLE XIII.—HOT-WATER CONTROL TEMPERATURES

Outside Temperature, °F.	Hot-water-temperature-control Point, °F.
0	140
10	130
20	120
30	110
40	100
50	90
60	80
70	70

The equipment used for accomplishing hot-water-temperature control according to Table XIII consists of an outside compensator and a temperature controller (page 192), the latter having its sensitive element located at some point in the water circulation of the heater or boiler, which in turn operates so as to regulate the source of heat.

CHAPTER VI

OIL-FUEL TESTS

Testing of Oil Fuels.—In the space which can be taken for this chapter on the testing of oils, only a few of the simpler and more important tests can be given. To make a complete report on the composition of a kind of oil fuel, obtained either directly from a refinery or from a dealer, it is generally advisable to send a sample to a competent professional chemist, preferably one with a varied experience in the analysis of oil fuels. Characteristic test methods will be given here, however, which should be serviceable for determining whether an oil when used as a fuel has the necessary vaporization properties for the intended service, and, in case of very light oils, also, the temperature property to withstand a reasonable amount of heating without danger of becoming inflammable. The heating or calorific value of fuel oil is also a very important test, and this will be explained on page 226. It remains therefore only to take up here, for oil fuels, the methods of determining specific gravity; flash, burning, and "end" points; viscosity; cloudiness; pour or cold point; carbon residue; water and sediment; and emulsification properties.

Specific Gravity of Oil Fuels.—The ratio of the weight of a sample of oil fuel to the weight of an equal volume of chemically pure water is called the specific gravity of the oil. Since the various types of petroleum oils are lighter than water, their specific gravities are consequently less than unity, or, in other words, the specific gravity of a petroleum oil is always expressed by a decimal or an equivalent common fraction. For example, if a gallon of a certain type of oil weighs 7.08 pounds and a gallon of pure water weighs 8.34 pounds, the specific gravity S of the oil is

$$S = 7.08 \div 8.34 = 0.85 \qquad (12)$$

An oil is tested for specific gravity most accurately with a sensitive chemist's balance in conjunction with a specific-gravity bottle. A conventional type is shown in Fig. 146. Bottles for

this purpose are made of thin glass and the weight of distilled water which they will contain is determined accurately and etched on the outside surface of the bottle.

Fig. 146.—ecific-grav-

The bottle is provided with a small ground-glass stopper having a capillary tube or hole drilled through it, so that when the bottle is filled to the top of the capillary tube, it will always hold the same volume of oil.

In determining the specific gravity, the bottle is filled with the oil to be tested, care being taken to avoid the formation of air bubbles. The stopper is then inserted and some of the oil will run out through the capillary tube. This excess should be wiped off so that the bottle will be clean and dry. It can then be weighed. After once determining the weight of the bottle filled with distilled water at 60°F., the bottle can be used without again weighing it with water.* The weight of the empty bottle should be ascertained from time to time to determine, more than for any other reason, whether it is clean. If it is found to weigh more than when new, obviously it needs cleaning. The weight of the oil in the bottle when it is full, divided by the weight of the corresponding amount of distilled water is the specific gravity of the oil being investigated. The oil tested should be at 60°F. when it is weighed in the bottle, as this is the standard temperature for the specific gravities of all oils.

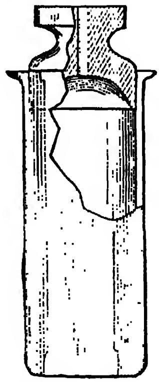


Fig. 147.—Hubbard specific-gravity tube.

For the determination of the specific gravity of very thick oils and greases, a type of bottle or tube known as *"Hubbard's"* (Fig. 147) is often used. It consists of a metallic tube with a ground-in stopper, having a slightly larger bore than the capillary tube in the glass stopper of the ordinary specific-gravity bottle.

Hydrometer.—In commercial practice the specific gravity of oils is usually determined by means of an instrument called a

* This suggestion is made because it is not always easy to obtain clean distilled water. Condensed steam from a surface condenser is usually sufficiently free from impurities and is, of course, distilled water.

hydrometer (Fig. 148). It is most conveniently used by filling a glass jar, preferably similar to the one in the figure, with the liquid to be tested and then inserting the hydrometer. The reading on the scale of this instrument when floating in a sample of oil is the specific gravity of the oil, and should be made with the eye at the level of the surface of the liquid, as shown in the figure and not above or below that level. The hydrometer shown has a thermometer combined with it, so that the temperature of the oil can be read on the scale of the thermometer stem. The "surface of the liquid" is here understood to mean the surface of the main body of the oil and not the level of the ring around the instrument due to capillarity. Hydrometers are made with two standard scales. One is the ordinary specific gravity scale graduated to correspond to the determinations of specific gravity as defined for determinations with the specific-gravity bottle; that is, it uses always the ratio of the weight of the liquid to the weight of an equal volume of water. The other is an arbitrary one known as Baumé's and is generally used by refiners and oil dealers. For short it is often called the "gravity" scale. Table XIV will be found convenient for converting one scale to the other. As a rule-of-thumb key to the two scales, it will be found useful to remember that 70°Bé. is 0.70 in specific gravity.

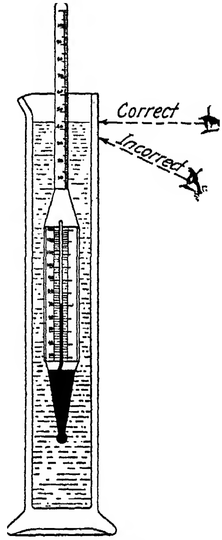


FIG. 148.—Hydrometer.

TABLE XIV.—SPECIFIC GRAVITIES EQUIVALENT TO BAUMÉ DEGREES

Baumé degrees	Specific gravity	Baumé degrees	Specific gravity
10	1.0000	60	0.7368
20	0.9333	65	0.7179
30	0.8750	70	0.7000
40	0.8235	75	0.6829
50	0.7777	80	0.6666
55	0.7567	85	0.6511

In order that specific-gravity determinations may be accurately compared, the standard temperature of 60°F. has been adopted.

This means that a statement of specific gravity of an oil at *standard conditions* implies that the value given of its specific gravity is that at the equivalent temperature of 60°F. for the substance and is relative to water at 60°F.*

The scale of specific gravity is scarcely ever used in practical work dealing with oils for lubrication or for fuels, and, instead, the Baumé scale is used. According to this scale, the specific gravity of water at 60°F. is called 10 degrees Baumé (10°Bé.) and *any liquid* that is heavier than water has a gravity designation that is less than 10°Bé.

In the oil industry, unfortunately, there are two Baumé gravity scales; one of these has been adopted by the U. S. Bureau of Standards and the other by the American Petroleum Institute (A.P.I.). The latter is called also the Tagliabue Baumé scale.

The relation between the Bureau of Standards Baumé scale and the ordinary specific-gravity scale for liquids lighter than water—which is the only case that applies to fuel oils—is given by the following equation:

$$\text{Degrees Baumé (Bureau of Standards)} = \frac{140}{\text{specific gravity at 60°F.}} - 130 \quad (13)$$

Similarly, the Petroleum Institute Baumé scale is given by a slightly different formula:

$$\text{Degrees Baumé (Petroleum Institute)} = \frac{141.5}{\text{specific gravity at 60°F.}} - 131.5$$

Table XIV corresponds to the values of the Bureau of Standards formula.

Checking Oil Deliveries by Specific Gravity.—The specific gravity of a fuel oil† has a useful commercial application for

* Practically, of course, there is little difference between the density of water at 60°F. and at, say, 20°F. less or 20°F. more.

† Specific gravity of a *lubricating* oil has no relation to its antifriction properties so that the terms "light," "medium," and "heavy" oil do not refer to specific gravities but to viscosity. These designations are misleading and go back to the time when it was thought that oils of high specific gravity had also high viscosity. In a general way, specific gravity of a lubricating oil indicates the type of crude oil from which the lubricant was made. For example, oils that have a density higher than 0.90 (less than 27°Bé) are

checking the grade of oil in a shipment. If an oil contract provides for the supplying of oil from a definite crude-oil base, and fuel oil of a given density has been giving satisfaction, it is likely that all oil shipments from that source having the same density will be equally satisfactory.

If the temperature of the sample of an oil that is tested is not at 60°F., a correction is necessary. There are charts and tables that can be used for making this correction quite accurately.* For practical applications, in order to obtain standard conditions for the heavier oil fuels, 0.05°Bé. should be added for each degree Fahrenheit that the temperature of the sample tested is above 60°F.; and similarly for the lighter fuel oils, 0.10°Bé. should be added for each degree Fahrenheit above 60°F. of the sample.

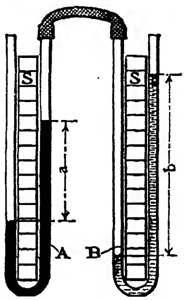


FIG. 149.—Specific-gravity device including U-tubes.

Simple Device for Determining Specific Gravity.—Sometimes it is necessary to determine the specific gravity of oil fuels when suitable *instruments are not available.* Figure 149 shows a device which can be conveniently used in such cases. It consists of two U-tubes, connected together by rubber tubing as shown. Each U-tube is provided with the usual scales for observing the difference in level of the liquids in each of the tubes. One of these tubes is to be filled with clean distilled water (condensed steam may be used) and the other with the liquid to be tested. When a slight pressure is produced in the tubes A and B, as, for example, by blowing with the mouth, the differences in the levels of the liquids in the two tubes are to be observed. The difference in level will be greater, of course, in the tube having the lighter liquid. The ratio of the difference in level in the U-tube containing water to the difference in the level in the U-tube containing the oil being tested is the specific gravity required. In the figure, if the U-tube A contains distilled water and the tube B the oil being tested, so that the water is displaced a inches and the oil

likely to have been made from Texas crude oil, while those lubricating oils which have a density considerably less than 0.90 have probably been made from Pennsylvania crude oil.

* R. S. Danforth, "Pressure Loss in Oil Pipe Lines," Kinney Manufacturing Co., Jamaica Plain, Boston, Mass., 1920.

b inches, then the *specific gravity* is $a \div b$. This sort of device can be made up anywhere where glass and rubber tubing are available.

Specific Gravity in Relation to Properties of Oil Fuels.—The temperature at which vaporization occurs for the various grades of petroleum distillates is somewhat related to the specific gravity of the oil. In other words, it may be stated as a general rule that the vaporization or boiling temperature of light petroleum oils is very much less than the vaporization temperature of most kinds of heavy petroleum oils. Because of this relation, until recent years, specific gravity was used as a criterion for the grading of oil. There was a time when most of the *gasoline* used was purchased on specifications of specific gravity and, until very recently, fuel oils were purchased on the basis of similar specific-gravity specifications, based usually on the so-called "gravity" in degrees Baumé. Especially since crude oils from the southwest have appeared on eastern and middlewestern markets, however, the unsuitableness of this specification became apparent. It is not unusual for two samples of fuel oil that have the same specific gravity to have quite different properties when used as fuel in oil burners. It is obvious that the suitable mixing of light and heavy samples of petroleum distillates will produce a fuel oil of any desired specific gravity and that then the specific gravity would be no criterion at all as to the suitableness of the oil mixture for use in a particular type of oil burner. However, mixing, commonly called "blending," is usually necessary in the commercial operation of an oil-refining plant since the wide variations in market demand cannot be economically met by a method of refining that would produce the desired grade of fuel oil by the simple collection of vapors from a still (page 11) only during the time that the required grade of oil is being vaporized. There is the further difficulty with the specific-gravity standard of fuel-oil grading that the operators of the refinery do not have enough data from information regarding specific gravity alone to produce the types of fuel oil that will be most suitable for the service that is required of different oil burners.

Flash-point Test and Fire (Burning-point) Test of Oil.—At one time a very important part of the specifications for oil was the flash point and the fire test. The *flash point* indicates the temperature at which an oil gives off vapors in such amount that, in

combination with air, they form an inflammable mixture. Formerly the flash point was considered especially important because

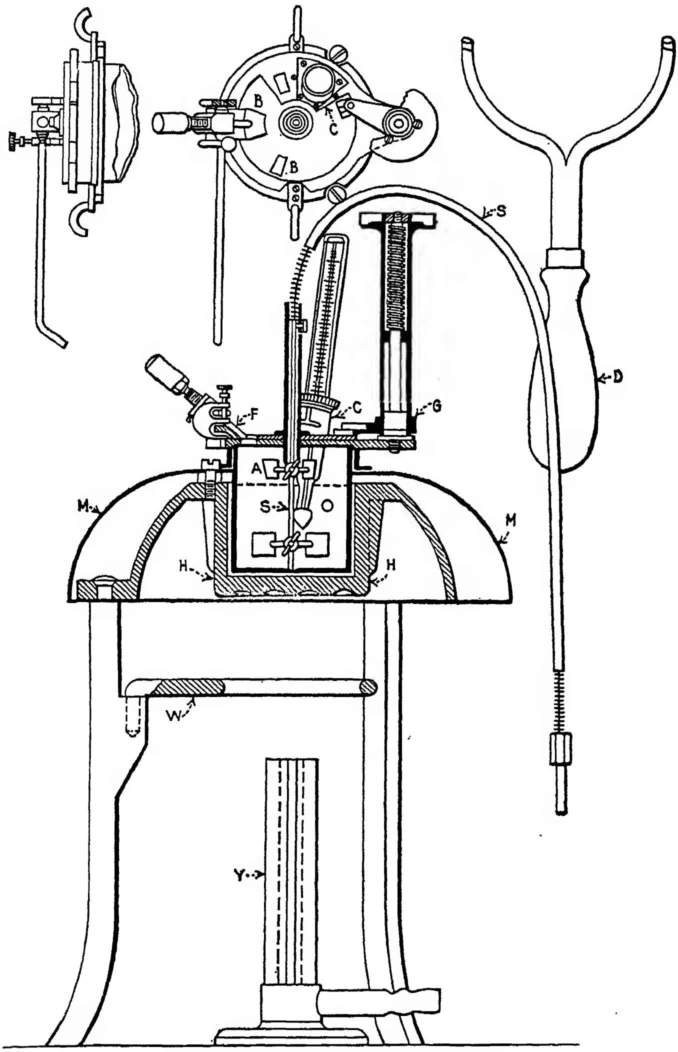


FIG. 150.—Pensky-Martens oil tester.

of its relation to the fire hazard in the storage and shipping of oils. When there was relatively little oil stored and shipped that was

volatile at low temperatures, the flash-point test of an oil was probably much more important than it is now, when oils of the gasoline group are being shipped and stored in so much larger amounts than any other petroleum product.

The *burning point* of an oil fuel is the temperature at which the oil ignites and continues to burn. The burning point is usually from 5 to 20°F. higher than the flash point.*

An oil fuel will not ignite itself merely because its temperature is slightly above the flash or burning point. Until a considerably higher temperature is reached, external ignition is necessary.

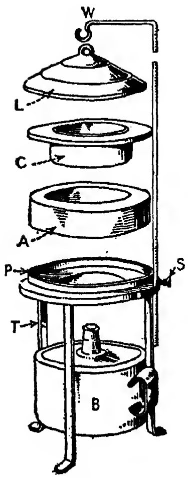


FIG. 151*a*.—Cleveland oil tester.

Apparatus for Determining Flash Point and Fire Test of Oil.—There are two kinds of apparatus that are used for flash-point and fire-test determinations of fuel oil, namely, (1) open type and (2) closed type. Among the *closed* type of apparatus for these determinations, the *Pensky-Martens instrument is now generally accepted as the standard* for the flash test. This apparatus is shown in considerable detail in Fig. 150. The Cleveland tester (Fig. 151*a*) is the type of *open* tester that is most widely used. The Pensky-Martens tester is the more accurate of the two, but the Cleveland open tester gives sufficiently accurate results for most practical work.

The Pensky-Martens Closed Tester.—The oil tester of the closed type shown in Fig. 150, called Pensky-Martens, consists of an oil container *O*, which is placed in a metal heating vessel *H*, provided with a mantle or covering *M* to protect *H* from heat loss caused by radiation. The oil cup *O* is closed by a closely fitting brass lid. Through the center of the lid passes the stirring mechanism, consisting of a slender shaft *S* carrying two propellers used for stirring, one of them rotating in oil, and the other in the vapor space just under the lid. The stirring mechanism is oper-

* Up to the end of the last century, many oils used for lubricating had flash or burning points under 300°F., so that a hot bearing on an engine or machine was a potential fire hazard. In recent years, however, lubricating oils have been so much improved in the refining processes that the flash and burning points of good-quality oils have been raised, so that they are now nearer 400°F. than 300°F.

ated by the handle *D*. The lid has four other openings, the position and size of which are accurately made (see top view in figure). One of these openings is circular and the thermometer collar *C* is concentric with it, the thermometer being inclined at an angle convenient for reading. The other three openings are opened and closed by a slide valve *B*; this valve is controlled by a spring and lever device *G*, which is rotated by the milled head at the top. One of these openings (middle) is used for inserting the testing flame, and the other openings for admitting air necessary for combustion. The test flame is controlled mechanically by the operation of the slide valve *B* which inserts the test flame into the space above the oil. With every turn of the milled nut *M*, the spring and lever device *G* is moved, so that the middle opening in the slide valve *B* comes opposite the orifice in the lid; and, at the same time a very small flame burning at the movable jet *F* is moved so that it comes very close to the surface of the oil that is being tested. This test-flame burner should have a tip opening of $\frac{1}{32}$ inch in diameter. A pilot-light burner is maintained near the test-flame burner, so that every time the slide valve *B* is open, the test flame is automatically lighted.

Test Procedure.—In order to start a test with the Pensky-Martens tester, the cup *H* is filled to a standardized marked level with the oil to be tested. The lid is then put in place, and the oil is heated somewhat rapidly at first, until its temperature is about 50°F. below the expected flash point. The temperature of the oil is then increased slowly, about 10°F. per minute, the temperature rise being conveniently controlled by the use of the wire gage *W*, as shown in the figure, just above the Bunsen gas burner *Y*. During this latter heating, the milled head *M* is turned somewhat slowly, so that the test flame is tilted about once a minute into the oil cup *O*. The temperature at which the first slight explosion due to the vapor ignition is observed is recorded as the *flash point* of the oil.

Cleveland Open Tester.—An open type of oil tester which is used a great deal in the commercial testing of fuel oils is shown in Fig. 151*a*. It is a simple device consisting of only six essential parts, which are: (1) A brass cup *C*, $2\frac{1}{2}$ inches inside diameter, and $1\frac{5}{6}$ inches deep; the side wall of the cup is $\frac{3}{16}$ inch thick, while the bottom is $\frac{1}{16}$ inch thinner.* (2) A brass plate *P* with

* Exact dimensions of this equipment are given in Diedrichs and Andre, "Experimental Mechanical Engineering," Vol. I, p. 919, 1930.

a circular depression to fit the rim of the cup. (3) A hard asbestos plate ¼ inch thick, with a hole to fit the cup. (4) A brass lid *L* which fits the cup. (5) A tripod *T* which supports the glass plate. (6) A nitrogen-filled etched-stem-glass thermometer having a bulb approximately ½ inch long, which is not larger in diameter than the stem. Heat is applied to the oil cup by the use of a Bunsen gas burner which should be protected from air drafts by a suitable shield; the latter may extend up to the level of the asbestos plate *A*.

Test Procedure.— In order to make a test of oil with the Cleveland open tester, the cup *C* is filled up to a standardized mark on the inside of the cup, which is about ⅜ inch below its upper edge. The asbestos ring *A* is then placed around the oil cup *C*, and the bottom of the cup is inserted into the depression in the plate *P*. The cup *C*, the plate *A*, and the plate *P* are then placed on the tripod *T*. In this position, the cup is heated by the flame from a suitable burner which is adjusted to heat the oil at a uniform rate of 10°F. per minute. The thermometer for observing the temperature of the oil may be conveniently suspended from a wire support *W* adjusted in height by means of a thumb screw *S* fastened to the side of the tripod *T*. The thermometer must be so located that its bulb is halfway between the center and the side of the cup and is completely immersed in the oil; but it is lower and must be as nearly as possible about ½ inch from the inside bottom of the cup. If the special flash-test thermometer provided by the manufacturers of this equipment is not used, correction for emergence of the stem (page 232) of the thermometer must be made. It is necessary to be careful in making this test to be sure that the temperature of the oil is continually rising, as any recession at about the flash point or the burning point would invalidate the results. In other words, the temperature of the oil must be kept steadily increasing at the specified rate throughout the test, except that in the early part a higher rate of heating (to about 50°F. below the expected flash point) is allowable. The test flame should preferably be from a very small gas burner with a "tip orifice" not much larger than the one in the Pensky-Martens flash tester; but instead of the gas flame a long splint of wood or a wax taper may be used satisfactorily. The flame of whatever kind should not be more than about ⅛ inch in length and should be drawn across the cup in

the horizontal plane of its top edge. The test flame should be applied in this way at 5°F. intervals throughout the test. The temperature at which the first flash of vapor combustion takes place near the surface of the oil is to be noted and recorded as the *flash temperature,* which means that this is the point at which the oil liberates its vapor at a sufficient rate so that it may be ignited. The flash point must not, however, be confused with a bluish halo that sometimes surrounds the test flame at a temperature much below the flash point. Obviously, air drafts must be carefully avoided in a testing apparatus of this kind, and it is a good precaution partially to darken the room where a test is being made, so that the first flash may be observed with certainty.

By continuing the application of heat, the vapor will be raised in temperature and distilled from the surface of the oil at a sufficient rate to maintain combustion indefinitely. The temperature of the oil at this point is called the *fire test* or the *burning point.* When this temperature is reached, the thermometer must be removed and the flame smothered with the lid L which is a part of the testing equipment. Emergent-stem correction (page 232) must be made for the fire test or burning point in the same way as for the flash point, if the thermometer is not the one provided by the manufacturer for the apparatus for which stem correction has been made when marking the graduations.

Heating Heavy Fuel Oil to Proper Temperature.—In mechanical atomizer systems fuel oil is heated for the sole purpose of reducing the *viscosity*—in other words, of increasing the fluidity. This is essential, primarily, as an aid to fineness of atomization; but occasionally, with oils extremely viscous at low temperatures, some heating is necessary to reduce the viscosity so that the pumps may handle the oil at full capacity. The effect of heat on the viscosity of various oils is shown by the temperature-viscosity curves in Fig. 151*b*. Unless the viscosity of the oil is reduced to the proper point, the atomization will not be satisfactory, no matter how perfect the design of the burner and how correct the oil pressure may be.

Oil Not to Be Heated above Flash Point.—The proper temperature to which the oil should be heated is that temperature which reduces the viscosity to between 2° and 4° Engler (page 215), provided the flash point of the oil is not exceeded. Standard specifications of the U. S. Navy for fuel oil or any oil of equivalent

viscosity state that it shall never be heated above the flash point in any part of the system except at the atomizers.

Great care shall be taken to detect leaks in the fuel-oil system, especially if it happens to be necessary to heat the oil above the flash point.

The thinner the oil the finer will be the atomization produced. The greater the viscosity the more difficult it becomes for the atomizer to break up the oil into particles fine enough for its intimate mixture with air that is necessary for good combustion.

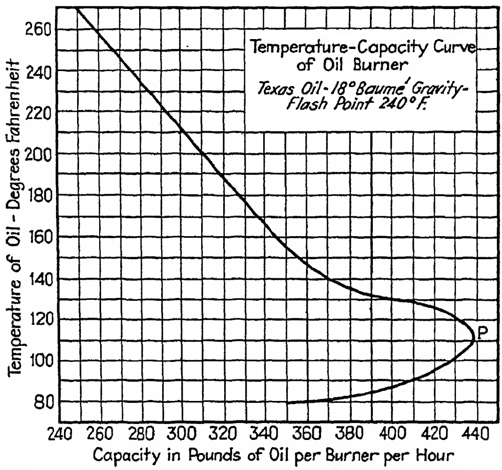


FIG. 151b.—Effect of temperature of oil fuel on combustion capacity of oil burner.

Those oils having a gravity of 20°Bé. (specific gravity 0.9340) and above will not be much reduced in viscosity by heating above 130°F. Inasmuch as mechanical atomizers will produce efficient atomization with oils at a viscosity between 2° and 4° Engler, there is no practical gain in heating the oil above the temperature that will give a viscosity between these limits.

Heating Viscous Oils.—The more viscous the oil the more necessary it is to reduce the viscosity to a low point to obtain good atomization; likewise it is more difficult to do so. To obtain best combustion it may sometimes be necessary to heat the oil to a temperature high above the flash point, which is dangerous unless extreme care is taken to guard against leaks in the oil lines. In addition to this objection there is the danger of breaking down

the oil, causing it to clog up the heaters and oil lines and to carbonize on the atomizing tips. Bearing these objections in mind, heating of viscous oils should not be greater than is absolutely necessary to obtain proper atomization and combustion. Such heating should never be carried above the flash point in any part of the system except at the atomizers.

It is important to remember that the capacity of a burner is increased by heating the oil to a so-called critical point. Beyond this point, however, additional heat actually lowers the capacity. This is shown in Fig. 151*a* which illustrates the results of capacity tests of a well-designed oil burner. During these tests the operating pressure was held constant while the temperature of the oil was varied over a wide range. The rapid drop in capacity, after the temperature is carried beyond the critical point *P*, emphasizes the importance of determining the correct temperature to be used. The capacity loss is due to the fact that heating of the oil increases its volume; even though this heating reduces the resistance of the oil to flow through the oil-service line and the atomizer of the burner. Less oil by weight is forced through the nozzle of the atomizer under a given pressure when the oil is too hot than when the temperature is just right for satisfactory atomization.

End-point Test.—A test of considerable importance, but one which cannot be readily made with ordinary laboratory apparatus, is for the determination of what is called the "end point" of fuel oil, meaning the temperature of the oil when all of a sample has been distilled; that is, when only the solid residue remains. In order to obtain the end-point temperature, special equipment is needed; and even then an accurate determination of temperature is difficult. Because of this difficulty the end-point test really begins with the noting of temperature when by the process of distillation 10 per cent by volume of the sample (condensed vapors) has been collected in a graduated vessel. The temperature is also noted when 90 per cent of the sample has been distilled, condensed, and cooled in the graduated vessel. This "10 per cent point" when occurring at a relatively low temperature, indicates that the fuel oil will easily ignite; and that the higher this temperature (corresponding to the 10 per cent point), the greater the difficulty will be in obtaining satisfactory vaporization for ignition. On the other hand, the 90 per cent point and also

the end point give some indication of the relative ease with which *complete* combustion can be obtained in an oil burner. It is more logical to use for this determination of relative complete combustion, the end point rather than the 90 per cent point; but because of the practical difficulty in obtaining correct determinations of the end point, the 90 per cent point is specified for fuel oils numbered 1, 2, and 3 (page 16). It is conceivable that a blended fuel oil may have light constituents so that the temperature at the 10 per cent point would indicate satisfactory ignition properties, but the end point or the 90 per cent point might show that it contained heavy constituents in such large amounts that complete combustion would, in most cases, be quite difficult to obtain. In Table III (page 17) no temperature values are given for end point and 90 per cent point for No. 4 fuel oil. It is an illustration of the less rigid specification requirement for the heavier fuel oils.

Fuel-oil Specifications (Commercial Standards).—In making up specifications of the important properties of the several grades of fuel oil, it should be kept in mind that the requirements specified must be rigid enough to make certain that the fuel oil when used in an oil burner will burn satisfactorily and, on the other hand, will permit sufficient allowance for possible variation, so that the cost of producing the fuel oil will not be excessive. In other words, the specifications for a fuel oil must be stated so as not to prohibit a reasonable amount of blending, if such blending will make a satisfactory fuel oil for the type of oil burner in which it is to be used. The commercial so-called "standard" specifications, as adopted by the oil associations as suitable for automatic oil burners, are summarized in Table II. These specifications are for six grades of fuel oil. Grades 1, 2, and 3 are intended for automatic domestic oil burners and are called "light," "medium," and "heavy" *domestic* fuel oils. On the other hand, grades 4, 5, and 6, which are listed in Table III, are called "light," "medium," and "heavy" *industrial* fuel oils. It will be noted that in Table III the grade 4 is suitable for use in automatic oil burners; while grades 5 and 6 are intended for types of burners that are equipped with preheaters (page 167); this means that these latter fuel oils are too heavy to be vaporized in an oil burner without first heating them. Grades 5 and 6 are usually low-priced residual oils which will necessarily vary a good deal in their properties. In fact, the variation is so great that the atomizing device

of the burner may have to be adjusted for nearly every new delivery of oil.

The relative rigidity of the specifications of fuel oils is readily noted in Table II where the specifications for No. 1 oil are relatively rigid, but those for the oils corresponding to the higher numbers in numerical order become less rigid in their requirements, because of the cheapness of these grades of fuel oil.

In writing specifications of fuel oil, it is the maximum flash point of oil that is specified, and the object of the specification is merely for safety protection in shipping, handling, and storage. The maximum value given in the specification is useful for determining the relative ease of ignition of the oil when used in an oil burner. Every sample of fuel oil has, of course, only one flash point, the minimum and the maximum values being merely relative and being given to designate the *limits* of variation for both safety and easy ignition. In Table II, for example, the statement that the flash point for No. 2 oil is minimum 110°F. and maximum 190°F., means that the flash point of No. 2 oil must not be less than 110°F. for safe use and not more than 190°F. for satisfactory ignition in the type of oil burner for which No. 2 oil is required. There happens to be an overlapping of the values of flash point for the different number designations of the grades of fuel oil. For example, an oil that has a flash point of 135°F. might be, so far as flash point alone goes, either No. 1, 2, or 3. It is quite clear, therefore, that the designation of flash point alone does not determine, any more than specific gravity, the numerical grade of fuel oil. There is the further limitation by state laws in regard to low flash points. For example, in one state the sale of any oil for fuel purposes is prohibited if the flash point is less than 115°F. In that state, therefore, actually the flash-point specifications for No. 1 fuel oil are minimum flash point 115°F. and maximum 150°F.

Viscosity Tests.—Viscosity is another name for what is often called the stickiness or adhesiveness of oil. The importance of this quality of an oil for use in oil burners has been explained on page 205. The general statement may be made that viscosity is measured by the *ratio* of the time required for a *measured amount* of the oil to be tested to flow through a miniature orifice in the bottom of a cup-shaped container to the time required for pure water at a standard temperature to flow through the same orifice.

The apparatus used for making viscosity tests is called a "viscosimeter." In making the test for the viscosity of an oil, a plug valve is placed over the orifice in the bottom of the container which is then filled with a sample of the oil up to a definitely marked level; when the plug valve is removed, the time is taken for a measured amount of the sample of the oil to pass through the orifice. Then the time required for the same quantity of water is also observed. The ratio of the two time factors of flow is the viscosity (ratio method). The sample of oil is usually tested when the temperature is either 100° or 122°F., or at both temperatures. The most commonly used viscosimeters are the ones designed by Saybolt. The modification of his original design called the Saybolt Furol viscosimeter is the one that is most commonly used for testing fuel oils. The essential difference between the two pieces of apparatus is that the latter (Furol) has a somewhat larger orifice than the former. There is an advantage in this change in the original ("universal") design, for the reason that when the Saybolt universal instrument with the small orifice is used, a relatively long time is required for the passage through the orifice of thick fuel oils. A complete report of the viscosity of the oil must state the type of instrument used, the temperature of the oil, the temperature of the water, the time taken for a given quantity of the oil to pass through the orifice, and the time required for the same quantity of water to pass through. It is quite common to report Saybolt universal readings at 100°F. and Saybolt Furol readings at 122°F.

It is a common practice to specify with respect to the two viscosimeters that have been explained, *only the number of seconds* between the time that the oil level passes a standard level point near the top of the container in its discharge from the orifice and the time when the container is completely empty. The difference in time between the beginning of this measured flow and the end is recorded in seconds. Thus, in the rules and regulations of the fire marshal of an eastern state there is this specification as to the viscosity of oil fuels as follows:

1. *Light fuel oil* is any oil for use as fuel which has a maximum viscosity of 125 *seconds* at 100°F. (Saybolt universal) or 100 seconds at 122°F. (Saybolt Furol).

2. *Heavy fuel oil* is any oil for use as fuel which has a maximum viscosity of 125 *seconds* at 122°F. (Saybolt Furol).

It is comparatively easy to adjust an oil burner for any consistent and reasonably low viscosity; but whenever there is a considerable change in the viscosity of the fuel oil used, a readjustment of the oil burner is necessary. For this reason No. 4 oil has given some trouble when used in automatic oil burners. On this account the National Board of Fire Underwriters will only approve automatic oil burners for No. 4 fuel oil if the maximum allowable viscosity is not more than 70 seconds (Saybolt universal) at 100°F.*

Viscosimeters are instruments designed to determine the viscosity of fuel and lubricating oils. There is no generally accepted standard for such tests, as various types of instruments are used, and the results with different instruments will often vary considerably. Unless the names of the designer and maker of the instrument used and the amount and temperature of fuel oil are stated, results may be almost meaningless.

It is generally considered necessary to make determinations of the viscosity of oil fuels at 70°F., and again at about 120°F. Very often it will be observed that, of two samples of oil fuel showing the same viscosity at 70°F., one will test considerably higher at 120°F. than the other.

Types of Viscosimeters.—One of the simplest viscosimeters, and one that is used in various modified designs for determining the viscosity of fuel oils, is shown in Fig. 152. It consists of a metal cup with an orifice at the bottom, surrounded by an outer vessel—also made of metal—which for low-temperature determinations is filled with water. For tests at temperatures above the boiling point of water the outer vessel is filled with mercury or with some kind of fuel oil vaporizing at a temperature higher than that required for the tests to be made. The outer vessel is circular but has a side extension shown on the right-hand side in the figure, under which a gas burner or an oil lamp can be placed for heating the liquid surrounding the inner cup containing the fuel oil to be tested. By this means the fuel oil in the cup can be heated uniformly to the desired temperature. The orifice is kept closed by means of a ball valve on a rod which extends up through the cover of

* Viscosity-test methods of oil are given in considerable detail in "Power Plant Testing" by James A. Moyer, 4th ed., pp. 524–536, (McGraw-Hill Book Company, Inc., New York,) 1934.

the cup. The ball valve may be lifted to allow the flow of fuel oil through the orifice by pressing down with the finger on the end of the lever *A*. The handle *H* is provided for lifting out the oil cup so that it can be easily cleaned. A thermometer *T* indicates the temperature of the fuel oil. For draining the water, mercury, or fuel oil from the outer vessel, a cock *C* is provided, and a glass cylindrical flask accurately graduated in cubic centimeters is supplied for measuring the discharge from the orifice.

To operate this apparatus, first fill the oil cup with about 200 cubic centimeters of the oil to be tested. In this apparatus it is necessary always to start the test when there is exactly the *same volume of fuel oil in the cup;* otherwise there will be variable heads (pressures) on the orifice for different tests, introducing corresponding errors in the flow of the fuel oil to be tested. In preparation for low-temperature tests the outer vessel is filled with water which is then heated until the fuel oil to be tested is at the required temperature. Maintain this temperature constant for 2 or 3 minutes and then place a 50-cubic centimeter flask under the orifice. By removing the ball valve start the flow of fuel oil, observing the time as accurately as possible, preferably to the fraction of a second. When the level of the fuel oil in the flask has reached the 50-cubic centimeter mark, close the ball valve and again observe the time. The number of seconds required for 50 cubic centimeters of fuel oil or any other liquid to flow through the orifice is called the *time viscosity*. Usually instruments of this kind have the *water viscosity* marked on the name plate. This is the number of seconds required for 50 cubic centimeters of distilled water at 60°F. to discharge through the orifice. The water viscosity should be checked from time to time because there is sometimes a small accumulation of grease in the orifice which may remain unobserved and would reduce the actual or effective size of the orifice. Some basis for comparison of viscosity determinations made by the various types of viscosimeters which depend in principle on the discharge from an

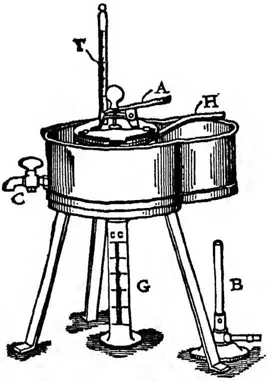


Fig. 152.—Scott's viscosimeter.

orifice can be obtained by calculating what is called the "specific viscosity." This is the time viscosity divided by the water viscosity. Thus, if for a given apparatus the time viscosity of a liquid is 120 seconds and the water viscosity is 10, then the specific viscosity is 12.*

Saybolt viscosimeter is in many respects a very satisfactory instrument for measuring relative viscosity. Because of the ease with which it can be operated and the simplicity of its action, this instrument has been accepted by the U. S. Bureau of Standards, the American Society for Testing Materials, and the American Petroleum Institute as the standard instrument for the measurement of the viscosity of oil. This instrument is shown in Fig. 153 and consists in its essential parts of a cup which has a small orifice at the bottom for the discharge of the fuel oil which is put in at the top of the cup and filled to a standard level.†

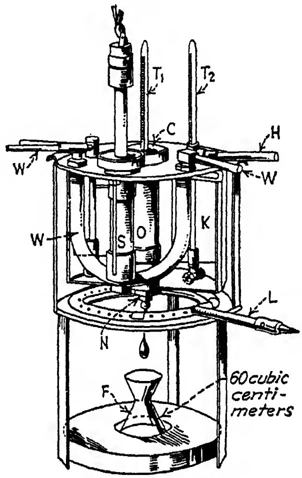


FIG. 153.—Saybolt viscosimeter.

The Saybolt universal viscosimeter is made entirely of metal. An oil tube *O* is provided at the top of the instrument with an overflow cup *C*, and at the bottom with a small outlet orifice through which the oil to be tested flows into a flask *F*, the capacity of which, when filled to the mark on its neck, is 60 cubic centimeters. The lower end of the outlet tube containing the orifice is enclosed by a larger tube in which a cork *K* is to be inserted that forms

* Sometimes when fuel oils of very different specific gravities are to be compared, a correction is applied to offset the difference in flow through the orifice, which causes the heavier oil to flow faster than a lighter one. Thus we obtain the *gravimetric viscosity* for comparison which is determined by dividing the specific viscosity by the specific gravity. For nearly all practical work the specific viscosity gives a sufficiently good basis for comparison of fuel oils.

† The only force available for driving the oil through the orifice in such an instrument is that of gravity, and the force holding the fuel oil back in the cup is its viscosity or what may be called its internal resistance. The time required for the standard quantity of oil to flow through the orifice will depend on both the viscosity and the specific gravity of the fuel oil.

a closed air chamber, the cork preventing the flow of fuel oil through the orifice until the cork is removed and the test is started. The oil tube O is set in a jacket which may be heated by a pipe W in which there is a circulation of steam or water that

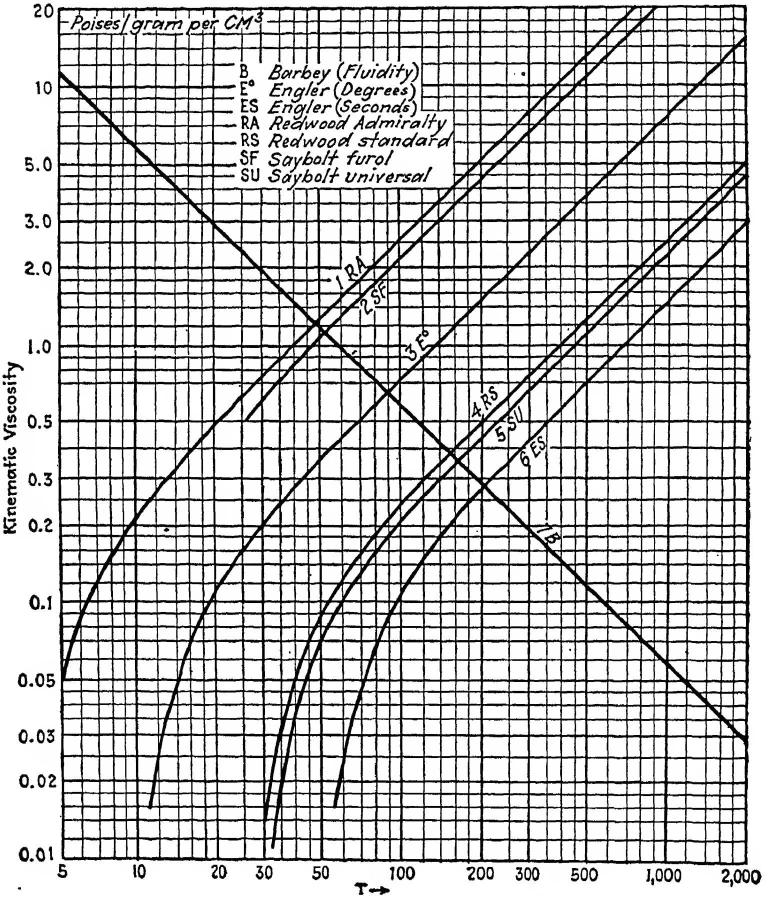


FIG. 154.—Diagram for comparison of viscosity determinations of oil.

is warmed by a gas flame or by an immersed electric heater. The pipe W for heating the oil bath may also be used to carry cold water through it to reduce the temperature of the bath, if it is too high for the purpose of the test that is to be made.

Saybolt Furol Viscosimeter.—When the viscosity of oily, viscous petroleum products like heavy fuel oil or road oil is to be determined, the Saybolt standard viscosimeter is not suitable and the so-called Saybolt Furol viscosimeter is used instead. The Furol type has an orifice that delivers oil volume at 10 times the rate of the standard type. When the Furol instrument is used, viscosity results are usually stated as "Saybolt Furol" at 70° or 100°F.

Redwood's and Engler's viscosimeters are practically the same as Scott's (Fig. 152). Redwood's is largely used in England and Engler's has been officially adopted by the German government. None of the different types described here have orifices of exactly the same size.

The viscosity scales of all industrial types of viscosimeters using the *efflux* (outflow) *principle* have arbitrary values. A chart for making conversions from the readings of one type of viscosimeter to another type which has been prepared and published by the Society of Automotive Engineers* is given in Fig. 154. It will be noted that the curves in this figure have been plotted on *logarithmic scales* (page 214). When such data are plotted in this way, nearly straight lines are obtained, except for very thin oils having a Saybolt *standard* viscosity of less than 140. This fact can be used for checking the results of viscosimeter tests. All the curves in the chart have a drooping tendency at the left-hand side of the curve sheet.

According to standard-Saybolt-viscosimeter tests, types of fuel oils have been classified as follows:

Light body....................	95 to 115 seconds at 210°F.
Medium body................	116 to 135 seconds at 210°F.
Heavy body..................	136 to 170 seconds at 210°F.

In the efflux type of viscosimeter, application is made of the fact that, when a liquid flows through an orifice, its rate of flow increases as the internal friction of the liquid decreases. In the application of this principle, therefore, it is possible to compare fuel oils for the purpose of determining the variation in the same fuel oil for different temperatures.

Absolute Viscosity.—The force which will move one square centimeter of plane surface with a speed of 1 centimeter per

* *Jour. S.A.E.*, vol. 10, p. 31, 1922.

second relative to another parallel plane surface from which it is separated by a layer of liquid 1 centimeter thick is called "absolute viscosity." It is usually expressed in poises, the *poise* being equal to 1 dyne second per square centimeter. At 68°F. pure water has an absolute viscosity of 0.01 poise. From the readings of the standard types of viscosimeters, absolute viscosity can be calculated by the use of the following equation:

$$V_a = g\left(xs - \frac{y}{s}\right) \tag{15}$$

where V_a = absolute viscosity, poises.
g = specific gravity.
s = viscosimeter reading.
x, y = constants for various viscosimeters as follows:

Viscosimeter	x	y
Saybolt universal	0.00207	1.8
Saybolt Furol...	0.0204	1.6
Redwood.......	0.0026	1.715
Engler..........	0.00147	3.75

Kinematic Viscosity.—The ratio of the absolute viscosity of an oil to its specific gravity at the temperature of the viscosity meas-

TABLE XV.—VISCOSITY EQUIVALENTS

Time universal Saybolt, seconds	Time Furol Saybolt, seconds	Time Redwood, seconds	Engler, degrees	Kinematic viscosity, poises
40	..	34	1.2	0.038
60	..	50	1.8	0.094
80	..	65	2.3	0.143
120	..	97	3.5	0.233
200	..	160	5.5	0.405
300	33	240	8.5	0.615
400	43	320	11.0	0.825
500	52	400	14.0	1.030

urement is called "kinematic viscosity" and is expressed by the following equation:

$$V_k = \frac{V_a}{g} \tag{16}$$

where V_k = kinematic viscosity.

V_a = absolute viscosity.

g = specific gravity at temperature of viscosity measurement.

Table XV gives for a few values the viscosity equivalence for the readings of the universal Saybolt, the Furol Saybolt, the Redwood, and the Engler viscosimeters.

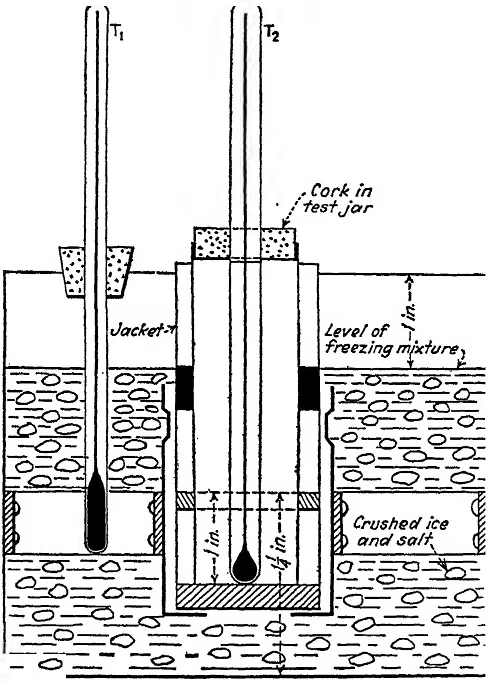


Fig. 155.—Cloud-test apparatus.

Cloud Test of Oil.—Oil fuels are frequently tested to determine the temperature at which paraffin wax and similar substances found in oil crystallize and separate from the oil. A test of this kind is called the *cloud test.* A simple apparatus for making this test of oil is shown in Fig. 155. It consists of a glass jar preferably a little more than 1 inch in inside diameter and about 5 inches high. The oil is poured into the glass jar until the level is about 1¼ inches above the bottom, the depth of oil being at least sufficient to permit reading the scale of the thermometer at

the level of the oil. For this test a special thermometer is needed which has a bulb that is only about 3/8 inch long. This thermometer is inserted into the jar through a tight-fitting cork which will hold it in a central position with the lower end of the bulb 1/2 inch from the bottom of the jar. The jar with the thermometer in place is then put in a metal- or glass-jacket container 5 or 6 inches high having an inside diameter at least 1 inch larger than the outside diameter of the inner or test jar. A disk of felt or cork about 1/2 inch thick is placed in the bottom of the jacket container; then the test jar containing the oil is placed centrally on the felt or cork disk. The jacket between the test jar and the jacket container is then filled with a refrigerating or freezing mixture which may consist of ice mixed with either calcium chloride or sodium chloride. For oils congealing or solidifying from 15° to 35°F., a satisfactory freezing mixture is made of cracked ice and sodium chloride in the portions of 1 part of salt to 20 parts by volume of cracked ice. For oils congealing at temperatures from −5° to 15°F., a larger percentage of salt is required than for the higher temperatures. In this latter case, there should be about 1 part of salt to from 3 to 5 parts of cracked ice. For still lower temperatures, as, for example, those as low as −20° to −25°F., a mixture of 1 part of *calcium* chloride to 3 parts of cracked ice may be used.

The cloud test is usually made by putting into the test jar, oil that has been heated in another vessel to a little more than 150°F. and has been cooled in the air to room temperature. The cooling is continued in the refrigerating bath, the jar being taken out at every reduction of 2°F. in its temperature below the point where congealing of the oils may be expected to begin. Care must be taken when removing the test jar not to move the thermometer, as even a small movement would hinder the congealing of the oil. When the lower half of the sample becomes opaque through chilling, the temperature of the thermometer in the oil should be taken and recorded as this is the *cloud-test temperature* of the oil.

Pour or Cold Test for Congealing of Oil.—There is often a great difference in the temperature at which oil fuels that have practically the same characteristics at room temperatures become viscous when they get very cold. In every sample of oil there are a number of different hydrocarbons (page 40). Each of

these hydrocarbon constituents has its own particular freezing point. When a number of the hydrocarbon constituents have freezing points at higher temperatures than most of the others in the oil, they will separate out and float on the surface of the oil. If the hydrocarbons which freeze at relatively moderate temperatures are present in sufficient quantities in the oil, they will cause the entire mass of oil to congeal. Oils which have a *paraffine base* (page 9), or, in other words, those that contain a considerable amount of paraffine wax, are likely to congeal at a much higher temperature than oils which have an *asphalt base* and contain no paraffine wax.

This is an especially important test for oil fuels which are used in winter and are stored in outdoor tanks (for instance, automobiles). The same apparatus that is used for the cloud test of oil may be used to determine the temperature at which a sample of oil will just flow, this being the *pour-test* temperature of the oil. In many cases the pour test of an oil may be taken immediately after the *cloud-test* temperature has been determined, as in most cases the cloud test has a higher temperature than the pour test. In any case, in making the pour-test determination (after the sample of oil has been cooled to about the expected pour-test temperature), for every further reduction of 5°F. in temperature, the test jar containing the sample of oil is taken from the jacket containing the freezing mixture and is held in an inclined position for not more than 10 seconds. The cooling is continued until the bottle can be held at an angle of 45 degrees without causing the oil in the jar to flow. When this point is reached, the previous test point (5°F. less than the point of solidification of the oil) is taken as the pour-test temperature of the oil. As a rule, the pour test should be completed in about ½ hour.

The simple method of making this test in a power plant is to fill a 4-ounce bottle with a sample of oil and place it where it will be exposed to low temperature, for example, in a brine tank of a refrigerating system. If the sample is frozen solid after an exposure for 24 hours, the thermometer should be put into the neck of the bottle so that the temperature may be observed as the bottle is heated. The pour test shows the temperature at which the oil in the bottle begins to flow. This method of testing requires that the oil shall be frozen without stirring or other

disturbances. This test although useful for oil fuels is not exactly satisfactory for testing the suitability of the oil for other uses as, for example, in a ring-oil bearing of an electric motor or in the clearance space between a shaft and its bearings which are, of course, agitated whenever the shaft moves, thus producing a tendency to prevent oil from congealing as it does in the pour test. The cold-test temperature as determined by this simplified method may be as much as 15° to 25°F. lower than the *actual*

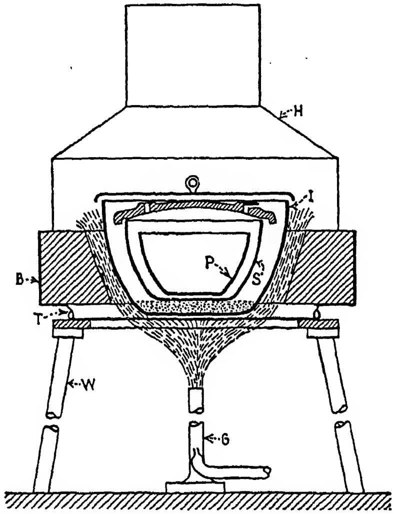


FIG. 156.—Conradson carbon-residue apparatus.

congealing point of the pour test. On the other hand, the oil in ring-oil bearings which have been warmed up by friction may congeal at a *higher* temperature than the pour test. The pour test made in a 4-ounce bottle as described above, or in a test tube as prescribed by the A.S.T.M.,* does not always indicate the temperature at which the oil will flow out of a barrel or a wide-mouthed can. As a rule, samples of oil can actually be poured at temperatures below the temperature of the pour test.

Carbon-residue Test of Oil.—If an oil fuel is heated to a high temperature in an enclosed container in which there is a limited supply of air, the greater part of the oil will be distilled and there

* A.S.T.M. is the abbreviation for the American Society for Testing Materials.

will remain a residue of carbon. The amount of this carbon residue in an oil fuel is an indication of the extent of its decomposition when used in oil burners intended for high-temperature vaporization (page 84). Carbon-residue determinations are generally made by the method introduced by Conradson, and

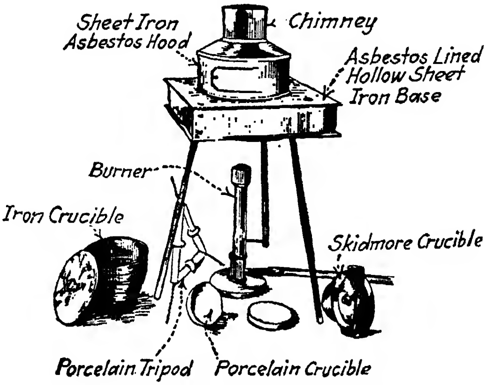


FIG. 157*a*.—Simple apparatus for determining carbon residue.

with the apparatus shown in Figs. 156 and 157*a*. This apparatus consists of the following equipment:

1. Porcelain crucible *P* (wide form), glazed throughout, 25- to 26-cubic centimeter capacity, 46 millimeters in diameter.
2. Skidmore iron crucible *S*, 45-cubic centimeter (1½-ounce) capacity, 65 millimeters in diameter, 37 to 39 millimeters high with cover, without delivery tubes and one opening closed.
3. Wrought-iron crucible *I* with cover, about 180-cubic centimeter capacity, 80 millimeters in diameter, 58 to 60 millimeters high. At the bottom of this crucible a layer of sand is placed about 10 millimeters deep or sufficient to bring the Skidmore crucible with cover on, nearly to the top of the wrought-iron crucible *I*.
4. Triangle *T*, pipe stem covered, with a projection so as to allow the flame to reach the crucible on all sides.
5. Sheet-iron or asbestos hood *H* provided with a chimney about 2 to 2½ inches high, 2⅛ to 2¼ inches in diameter, to distribute the heat uniformly during the process.
6. Asbestos or hollow sheet-iron block *B*, 6 to 7 inches square, 1¼ to 1½ inches high, provided with opening in center 3¼ inches in diameter at the bottom, and 3½ inches in diameter at the top.

Conradson's Method of Testing for Carbon Residue.—In testing a fuel oil in Conradson's apparatus (Fig. 156), approxi-

mately 10 grams of the oil are weighed in the porcelain crucible P, which is then placed within the Skidmore crucible S; the two crucibles (one inside the other) are put into the larger iron crucible I, care being taken that the Skidmore crucible is set in the center of the iron crucible. As shown in the figure, suitable covers are required over the Skidmore and the iron crucibles. The set of crucibles thus concentrically arranged are then placed upon a triangle T (pipe stem covered) which rests on a suitable iron chemist's stand W, the crucibles being surrounded by the asbestos or hollow sheet-iron block B which also rests on the triangle T. The stand and crucibles are then covered with the sheet-iron or asbestos hood or chimney H, which serves to distribute evenly the heat that is to be supplied during the test. The asbestos or sheet-iron block B serves as a shield for the flame from the gas burner G and guides the flame around the iron crucible I.

Heat is applied to the apparatus with a Bunsen or similar gas burner with a hot high flame which surrounds the iron crucible I, as shown in the figure, until vapors from the oil start to ignite over the crucible (usually from 4 to 7 minutes). When the vapors from the oil begin to ignite, the gas flame is lowered (to a height of 2 or 3 inches above the burner), and the first appearance of vapors must be carefully watched. After this period of "strong" heating, in order that the *oil-vapor flame* may not get too high, and to prevent the boiling of the oil in the crucible, the low height of the *gas flame* is required. The *vapor flame* should never exceed a height of 3 inches above the top of the chimney H and should be kept at an average of about 2 inches above that point during the period in which vapor escapes from the surface of the oil. After the vapor ceases to come off (as shown by inability to ignite it), the heat from the gas burner is increased to its maximum amount (about as it was at the start of the test) and kept at this height for 5 minutes. The bottom of the iron crucible I during this period of maximum heating should be red hot. At the end of this 5-minute period of high heat, the gas flame is put out and the crucibles are allowed to cool (with the chimney removed) for 5 minutes, after which the covers of the crucibles S and I are removed, and the porcelain crucible P is taken out and put into a desiccator where cooling is continued. When cooled to room temperature, the crucible with its residue

is accurately weighed. The entire test should be finished in about 30 minutes if the heat is properly regulated. The time, however, will depend somewhat on the kind of oil, as ordinarily a rather thin, low flash-point oil will require less time for this test than a heavy, thick, high flash-point oil.

In order to get accurate results, the dimensions of the apparatus used must be as nearly as possible the same as those specified in this description. Special precautions must be taken to observe the first appearance of vapors. In order to make this observation as accurate as possible, the gas burner may occasionally be momentarily removed to facilitate this observation. If, at any time during the test the vapor from the oil exceeds the 3-inch specification above the top of the chimney of the hood, the gas burner may be removed for a short interval until the size of the gas flame can be reduced sufficiently to keep the vapor flame about 2 inches above the top of the chimney.

Water and Sediment in Oil. Centrifuge Test.*—Fuel oils made by reputable refiners are free from water and sediment before they have been used, so that tests of oil for water and sediment are intended mainly for use in connection with *oils that have been used* in machinery and are to be burned for heating in an oil burner as, for example, in a garage. It is sometimes necessary, therefore to make tests of the oil removed from automobile-engine crank cases for a sediment determination, the sediment being due mostly to sand and dirt that got into the engine through the breather pipe and the carbureter and to bits of metal that have been worn from bearing surfaces and are corroded from those parts where water is present. It is often stated in this connection, although probably with not much basis in fact, that the amount of sediment found in samples of used automobile-engine oils is likely to be an indication of the carbon-residue properties of the oil.

The presence of a considerable amount of water as a liquid or a vapor in the fuel oil that is supplied to an oil burner is usually

* For more details of testing procedure, see Shoop and Tuve, "Mechanical Engineering Laboratory Practice," p. 154. Centrifuges and centrifuge tubes may be obtained from E. F. Mahady Company, Boston, Mass. Any convenient frame with whirling attachments of the required diameter that is suitable for the attachment of standard centrifuges may be used for this test.

indicated by sputtering atomization. It is therefore important that a good quality of fuel oil for oil burners should contain no appreciable amount of water. The maximum allowable amounts of water in fuel oils (Nos. 1, 2, 3, and 4) are given in Table II (page 16). Sediment is also objectionable though for different reasons. Sediment may plug the small pipes and nozzles discharging the fuel oil from the atomizing device of the oil burner. It will be noted in Table II that the total maximum amount of water and sediment allowable in Nos. 1 and 2 fuel oil is only half as large as that allowed for No. 3 oil, and that for No. 4 oil it is 10 times as much as for No. 3 oil.

One of the larger expenses connected with the manufacture of high-grade oils of any designation is the cost of removal of the impurities, these being especially water, sediment, and sulphur. This is one of the reasons why the specifications for the lower grades are more liberal than they are for the better grades of fuel oils. It is a matter to be kept in mind especially when considering the use of No. 4 oil in an automatic oil burner.

The method to be described of testing oil fuels by the use of a centrifuge, for the purpose of obtaining the amount of contained water and sediment, has had quite general commercial acceptance, although admittedly it is not very accurate, especially as to the amount of water; the results show in nearly all cases less than the actual water content. Nevertheless, as a general rule, it is needless to expect great accuracy from this method of testing, for the reason that there is always uncertainty as to whether the sample obtained for testing is really representative. Because of the difficulty in obtaining a good sample, it should be clear that the sampling should be done as carefully as possible. The centrifuge used for such testing is relatively simple in its parts and need not be designed with as great care as a similar apparatus intended for much higher speeds. The centrifuge for testing the water and sediment in oil fuels is usually made between 15 and 17 inches in diameter (tip to tip of the centrifuge) and revolves at a speed of about 1,500 revolutions per minute. The rotating member of the centrifuge may, however, have any other diameter which will give equal tip speed. Typical centrifuge tubes are shown in Fig. 157*b*.

Centrifuge tests of oil fuels are made by filling each of the centrifuges with a mixture of benzol (90 per cent pure) and the

oil to be tested, using 50 cubic centimeters of the benzol and 50 cubic centimeters of the oil. After the mixture of benzol and oil has been poured into each of the centrifuges, they are to be tightly corked or stoppered and then shaken vigorously until the contents are thoroughly mixed. The filled centrifuges are then to be placed in a water bath at 100°F. and are to be immersed to the 100-cubic centimeter mark for 10 minutes. After this immersion, the centrifuge tubes (usually two) are placed in their proper positions on diametrically opposite sides of the centrifugal frame to be whirled at the required speed for 10 minutes. At the end of this period, the centrifuge frame is to be stopped, the centrifuge tubes removed, and a reading taken of the volume of water and of sediment at the bottom of each tube. After these readings have been taken and recorded, the centrifuge tubes are again placed in the centrifuge frame and whirled for an additional 10 minutes, and, at the end of this time, when the centrifuge frame is stopped, readings of water and of sediment are again taken and recorded. This operation is repeated until the volume of water and of sediment in each tube remains constant for three successive readings. Usually, only four sets of observations are needed.

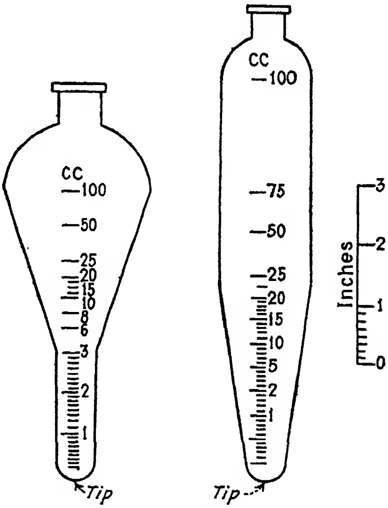


FIG. 157*b*.—Centrifuge tubes for water and sediment tests of oil.

Emulsification Test of Oil.—In some kinds of service, emulsification of oil is a desirable quality, while in other kinds of service it is undesirable.

In order greatly to increase the surface of oil that is exposed to air, an easily emulsified oil is preferred for some oil burners. As the result of emulsification, the oil particles become air-filled bubbles, each oil particle being then a hollow sphere enclosing at its center a small amount of air; the oil and air are then discharged together into the combustion chamber of the burner.

Some oil fuels are much more easily emulsified than others; and for some types of oil burners an easily emulsified oil fuel is preferred. In fact, emulsification is sometimes a desirable quality in oil fuels, while for lubrication especially for steam turbines an oil that emulsifies is unsatisfactory.

There is no standard emulsification test. Herschel, a specialist in the U. S. Bureau of Standards, has proposed the following method, which has received some acceptance: Into a glass container of about 100 cubic centimeter capacity, 20 cubic centimeters of the oil to be tested and 40 cubic centimeters of water are poured. Insert into this glass container a paddle about 90 millimeters long, 20 millimeters wide, and 1.5 millimeters thick. The glass container is then placed in a water bath where the temperature is maintained at approximately 130°F. This paddle is to be set up vertically in the glass container and with a suitable turning device is rotated at 1,500 revolutions per minute for 5 minutes. Record is made of the time required for separation of the water from the oil by taking readings at intervals of about 1 minute. The *demulsibility* figure D in the following formula is calculated from the rate at which the water separates from the oil per *hour* and is expressed by $D = 60v \div t$, in which v is the volume of oil separated out in cubic centimeters, and t is the corresponding time in *minutes*. Thus, if all the oil in the sample (20 cubic centimeters) separates from the water in 60 seconds, then the demulsibility figure equals $60 \times 20 \div 1$, or 1,200. On the other hand, if the sample of oil emulsifies so badly that only 15 cubic centimeters of it separate from the water in 15 minutes, the demulsibility figure $D = 60 \times 15 \div 15$, or 60.

Heating or Calorific Value of Fuel Oils.—By heating value of an oil fuel is meant the amount of heat produced by burning a given quantity of the fuel. This heating value is usually expressed in British thermal units (B.t.u.) per pound of fuel. Since, however, fuel oil is usually sold by the gallon, heating values per gallon are usually used.

The heating values of good grades of fuel oil do not vary very greatly per unit of volume as, for example, per gallon or per barrel. The heating value per pound of relatively light fuel oil is somewhat higher than heavier fuel oil, but on the other hand, the heavier fuel oil weighs more per gallon or per barrel than the lighter fuel oil. At any rate the variations in heating value of

fuel oils is rather small per gallon and is not very much more relatively per pound.

The only specification, but one which is difficult to apply in practice that has real value in regard to heat production in an oil burner, is the heating or calorific value in British thermal units (B.t.u.) per pound. From a large amount of data Professor DeWitt Taylor has developed the following formula:

$$\text{B.t.u. per pound} = 18{,}440 + 40(°\text{Bé.} - 10) \qquad (17)$$

where °Bé. is the specific gravity in degrees Baumé (A.P.I.). This formula applies well to the lighter fuel oils, but for heavier oils the substitution of 18,560 for 18,440 is recommended.

With this formula the data given in Table XVI have been calculated. Very little error is introduced by using the Baumé

TABLE XVI.—APPROXIMATE PROPERTIES OF DOMESTIC FUEL OIL

Grade	Degrees Baumé (A.P.I.)	Specific Gravity	Pounds per gallon	B.t.u. per pound	B.t.u. per gallon
No. 4	24	0.910	7.59	19,000	144,100
	26	0.898	7.49	19,080	142,900
No. 3	28	0.887	7.40	19,160	141,800
	30	0.876	7.31	19,240	140,600
	32	0.866	7.22	19,320	139,500
No. 2	34	0.855	7.13	19,400	138,300
	36	0.845	7.05	19,480	137,300
No. 1	38	0.835	6.96	19,560	136,100
	40	0.826	6.88	19,640	135,100

degrees of the U. S. Bureau of Standards in this formula instead of the A.P.I. Baumé degrees. In Table XVI, the fourth column, which is in pounds per gallon of fuel oil, has been obtained by multiplying the weight of a gallon of water (8.33 pounds) by the specific gravity of the oil. It should be kept in mind when reference is made to this table that the values given are obtained by reference to the specific gravity of the oil fuel and are not repre-

sentative of the heating values of oil fuels from any particular field. The data given are, therefore, useful only for comparative use and should not be given any more significance than this method of derivation justifies.*

* Methods of accurately determining the heating or calorific value of oil fuels by actual tests are given in "Power Plant Testing" by James A. Moyer, 4th ed., pp. 222–241, 250–251.

CHAPTER VII

HEAT

The relative amount of heat in a body is observed, in common experience, by the sense of touch—whether the body is a solid, a liquid, or a gas. By such experience certain sensations are recognized, as hot or cold; and then, with more accuracy, as degrees of *temperature.* When a hot and a cold body are brought together their temperatures become equalized. The hotter body always loses heat. The colder body always gains heat. This experience is the principal basis for all heat calculations.

When in the course of time it had been found that a more accurate method than that of the sense of touch was needed for heat determinations, methods utilizing the expansion of liquids came to be generally employed. Many liquids have a practically uniform rate of expansion between the limits of ordinary temperature ranges. Mercury in a glass capillary tube is especially suitable for temperature measurements.

Thermometers.—The most commonly used instrument for temperature measurement is the *mercury* thermometer. It consists of a glass capillary tube of very slender bore which has at its lower end a small closed bulb. The bulb is completely filled and the slender bore of the capillary tube is partly filled. Expansion or contraction of the mercury *in the bulb* causes a relatively long movement in the slender bore of the capillary tube. Heat has the effect of expanding the volume of mercury in the bulb and the "thread" of mercury in the tube is extended. On the other hand, cooling the bulb contracts the volume of mercury in the bulb and shortens the "thread" of mercury in the tube. The ordinary type of glass thermometer is made so as to have merely a vacuum in the capillary tube above the mercury. For use at higher temperatures the capillary may be filled with nitrogen gas when the thermometer is made. It will then be serviceable up to 1000°F. Thermometers made of quartz instead of glass and filled with nitrogen or carbonic acid gas can be used

for temperatures as high as 1500°F. Quartz thermometers are much stronger than those made of glass but are too expensive for ordinary commercial use.

Thermometer Scales. Fahrenheit and Centigrade.—Temperature as measured by a thermometer indicates the *intensity* of heat. For the purpose of comparing heat intensity a degree scale is used. On such a scale the freezing and boiling *points* of water are limiting points for thermometer graduations. On the scale called *Fahrenheit*, the freezing point is marked on the thermometer stem at the level of the mercury column when the bulb is in melting ice. This melting point of ice and freezing point of water is marked arbitrarily 32, and similarly the temperature at which water boils in an open container (at sea level) is marked 212. The distance on the capillary tube or stem of the thermometer between these two marks is divided into 180 equal spaces, each of which is called a *Fahrenheit degree*. The same spacing for temperature comparison may be extended downward below 32° and upward above 212°. This Fahrenheit scale of temperature is the one in general use for all work that is likely to be associated with oil-burner operation or testing.

Another scale for temperature measurement, called centigrade, uses the same two limiting points as the Fahrenheit scale, but the freezing point of water is marked zero and the boiling point of water in an open vessel at sea level is 100. The intervening distance on the thermometer stem is divided into 100 equal divisions that are also called degrees. The zero value in centigrade degrees for freezing water and the decimal basis of temperature differences in terms of the number of degrees between freezing and boiling water make heat computation much more simple when using the centigrade scale instead of the Fahrenheit scale.

Conversion of Temperature Scale Units.—Temperatures in centigrade degrees are converted into Fahrenheit degrees by multiplying the centigrade degrees by $9/5$ and adding 32, or in equation form:

$$\text{Fahrenheit degrees} = (9/5 \times \text{centigrade degrees}) + 32 \quad (18)$$

and similarly

$$\text{Centigrade degrees} = 5/9 \times (\text{Fahrenheit degrees} - 32) \quad (19)$$

For example, if 122°F. is to be changed to centigrade degrees, it is first necessary to subtract from the Fahrenheit degrees the number 32 and then multiply this difference, that is, 122 − 32 or 90 by $\frac{5}{9}$. The equivalent centigrade degrees are 50.

Correcting Temperature Errors.—One of the principal sources of error in temperature measurement is the natural tendency toward temperature equalization. This tendency which causes the flow of heat from regions of higher to regions of lower temperatures must always be borne in mind, and the effect of any possible flow on the reading of the instrument must be determined. For example, if a thermometer is inserted in a pipe in which superheated steam or a highly heated gas is flowing, it is commonly assumed that the thermometer acquires the temperature of the steam or gas. As a matter of fact, with temperatures between 500° to 600°F. inside the pipe and temperatures of 50° to 100°F. outside the pipe, there may be an error in temperature measurement varying from 1° to 2° to as much as 40° or 50°F., the thermometer indicating too low a temperature.

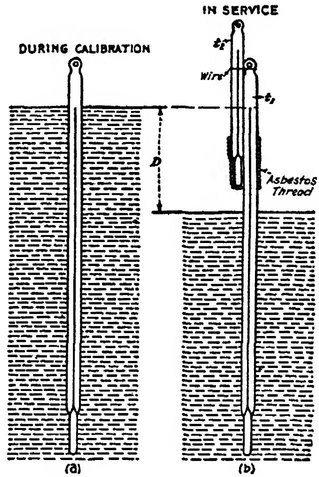


Fig. 158.—Arrangement of primary and secondary thermometers for stem-exposure tests.

The simplest method of determining the error in the temperature readings taken with a thermometer is to compare it with a so-called "standard" thermometer that has been calibrated in a well-known State or National testing laboratory such as the U. S. Bureau of Standards, Washington, D. C. The cost of such calibration of a thermometer for use as a standard for comparison with thermometers of which the errors are to be *obtained* is usually smaller than would be expected. When the "standard" thermometer is calibrated in a testing laboratory, the stem or capillary tube is immersed in the calibrating liquid approximately to the level of the top of the mercury column in the thermometer. However, in the actual use of thermometers in practical work, frequently only the bulb is immersed, or at best

only a short part of the stem, so that the stem at the point where the reading is taken will be at a different temperature from that of the bulb, and consequently the mercury in the stem will not expand proportionately with the mercury in the bulb. In order to correct for this error, a second and smaller thermometer may be used for calculating the correction to be applied for such *stem exposure.* This second thermometer should be attached to the midpoint of the exposed mercury column of the thermometer in "primary" use, so that it will give the mean temperature of the exposed mercury column. The arrangement of "primary" and "secondary" thermometers when used in this way is shown in Fig. 158.

Observed temperature readings are corrected for errors introduced by *stem exposure* by the use of the following equation* when the temperatures are in Fahrenheit degrees:

$$\text{Correct temperature (°F.)} = T_f + 0.00009 \times N_f \times (T_f - t_f) \tag{20}$$

where N_f = number of Fahrenheit degrees of exposed mercury column.

T_f = observed temperature, Fahrenheit degrees.

t_f = mean temperature, Fahrenheit degrees of exposed mercury column.

Similarly the equation for stem correction of thermometers marked in centigrade degrees is

$$\text{Correct temperature (centigrade)} = T_c + 0.00016 \times N_c \times (T_c - t_c) \tag{21}$$

where N_c = number of centigrade degrees of exposed mercury column.

T_c = observed temperature, centigrade degrees.

t_c = mean temperature, centigrade degrees of exposed mercury column.

Low-temperature Thermometers.—Very low temperatures cannot be satisfactorily observed with mercury thermometers. They become unreliable at about minus 35°F. For low temperatures glass thermometers are filled with alcohol and will then be

* Special cases of thermometer stem exposure are explained in detail in Moyer, "Power Plant Testing," 4th ed., pp. 45–59, 1934.

fairly accurate to minus 50°F. For observation in glass thermometers alcohol is usually colored red. Aniline is also used for low-temperature thermometers, and no coloring is needed as its natural color is red.

Thermocouple Pyrometers. Electrically Operated Thermometers.—A thermocouple is made by welding together two wires of different metals or alloys to form a complete electric circuit. An electric current is generated at the junctions of the wires in this circuit, which can be measured by a galvanometer or very sensitive *voltmeter* when connected in series with the two wires, as shown in Fig. 159, when the two junctions H and C are at different temperatures. If the cold junction C is always maintained at the same temperature, the scale of the current-measuring instrument V can be graduated to read directly the temperature of the hot junction.

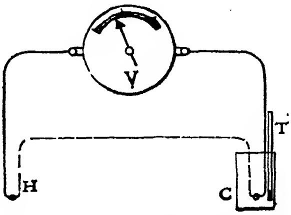


FIG. 159.—Thermocouple pyrometer.

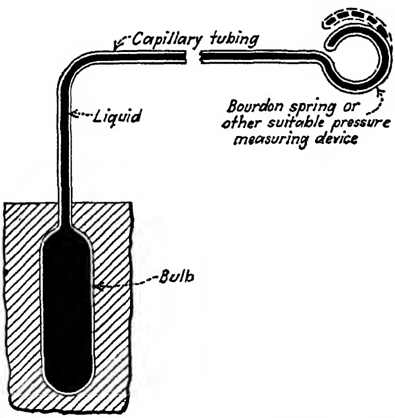


FIG. 160.—Bourdon-tube type completely filled with liquid.

Electric-resistance pyrometers depend for their action on the variation of the resistance of metals as the temperature changes, the resistance changes being measured usually by a Wheatstone-bridge instrument method. For temperature measurements up to about 600°F. a nickel resistance wire is used, and for higher temperatures at which a nickel wire would be overheated, a platinum wire can be used.

Bourdon-tube Thermometers.—Figures 160 and 161 show a type of temperature-measuring instrument which depends for its operation on the expansion of a gas, a vapor, or a liquid sealed in a copper or nickel bulb, and a Bourdon tube, the bulb being connected to the Bourdon tube by a small-bore flexible-metal tube. When the liquid or fluid expands, there is a movement of the Bourdon tube outward from its center, which can be made to move a pointer over a graduated scale in proportion to the increase in temperature.

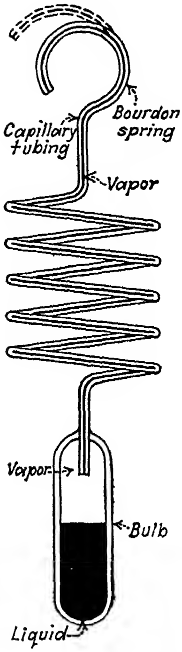


FIG. 161.—Bour- erated by vapor pressure.

The Bourdon-tube device (Fig. 162) is essentially an elastic element which is arranged to move a suitably attached pointer or needle over a graduated scale to indicate the degree of temperature to which the bulb is exposed. The most common form of such a device is a hollow brass or steel tube of elliptical cross section which is bent into the shape of an arc of a circle.

Radiation Pyrometers.—For temperatures above 2500°F. radiation pyrometers similar to the one illustrated in Fig. 163 are most suitable. They can also be used in many places where it is almost impossible to locate a pyrometer of any of the other types. The principle of operation is that the energy radiated by a so-called *black body* is proportional to the fourth power of its absolute temperature. The instrument illustrated consists of a cylindrical case set upon a tripod. This case contains a concave mirror and a lens (or lenses) which, when properly adjusted and focused on a hot body, concentrate the heat rays upon a small thermoelectric couple inside the case. Copper wires connect this couple with a very sensitive portable galvanometer located where it can be read conveniently. The most modern instruments of this kind are provided with scales indicating directly degrees of temperature. Figure 163 shows a section of the telescope used in connection with this pyrometer. The concave mirror *M* receives the heat rays and focuses them at *F*, where a small thermocouple is located. To assist in pointing the telescope, an eyepiece *E* is provided

through which a reflected image of the hot body can be seen. The rack R and the pinion P, moved by a thumbscrew outside

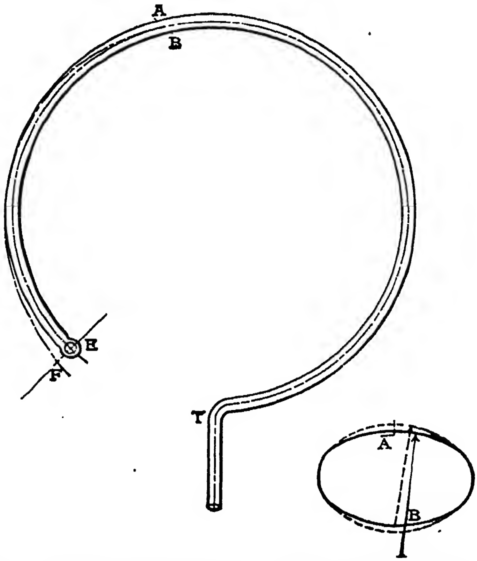


FIG. 162.—Bourdon-tube device for pressure-type thermometers.

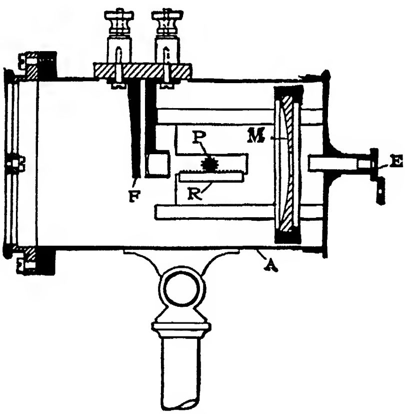


FIG. 163.—Radiation pyrometer.

the case, serve for adjusting the focus of the mirror. In the center of the field of view, as seen in the eyepiece, the thermocouple is seen as a black spot, and this must be overlapped on all

sides by the image of the hot body to obtain the correct temperature. It is interesting to observe that the distance of the telescope from the source of heat does not affect the reading of the instrument. When the telescope gets nearer the hot body, the mirror M receives, of course, more heat, but at the same time this greater amount of heat is distributed over a proportionally larger image and the intensity of the heat remains the same.

Radiation pyrometers are calibrated in terms of the radiation from a black body, which is approximately realized by a uniformly heated enclosure. It is only for black bodies, such as carbon and coal, that the temperature is exactly proportional to the fourth root of the heat energy. Readings obtained when measuring the temperature of a body not inside a closed chamber with hot walls will in some cases be very much lower than the true temperature. For a piece of heated coal, the error is very small owing to lack of enclosure, while in molten copper or tin with a clean surface the temperature reading may be 100°F. too low. Conditions as regards enclosure are, however, satisfactory in most practical cases where the instrument is frequently used, such as taking the temperature of boiler furnaces, gas producers and retorts, as well as also annealing and hardening furnaces. Error due to the furnace door being open for an instant when the observation is to be made is practically negligible, especially as these instruments are actually calibrated under this condition. If excess of air in a furnace is likely to reduce the temperature while sighting, a large tube of cast iron or fire clay closed at the end toward the fire can be built into the furnace wall. By sighting through the open end upon the closed end, which should be at the furnace temperature, very satisfactory results are obtained.

Observations made with such pyrometers of incandescent bodies or gases do not give the true temperature. It is generally assumed, however, that they can be used to measure fairly accurately the temperature of heated chambers when focused upon the walls, because of the reflection going on in all directions. In most cases the flame temperature can be taken as the same as that of the surrounding walls.

A relatively large area is usually required to sight radiation pyrometers. It is stated that the distance from the telescope

to the hot body can be as much as 30 times the diameter of the hot body and the telescope can be taken as much nearer as desired without changing the reading of the instrument. Before taking observations, the pointer of the galvanometer must be set at zero, the instrument receiving no heat rays during this adjustment. The readings of temperature made with such instruments are obviously the difference between the temperature of the hot body and of the room.

Optical Pyrometers.—Another type of pyrometer, based in principle upon the measurement of the brightness of the hot body by comparison with a standard lamp, is shown in Fig. 164.

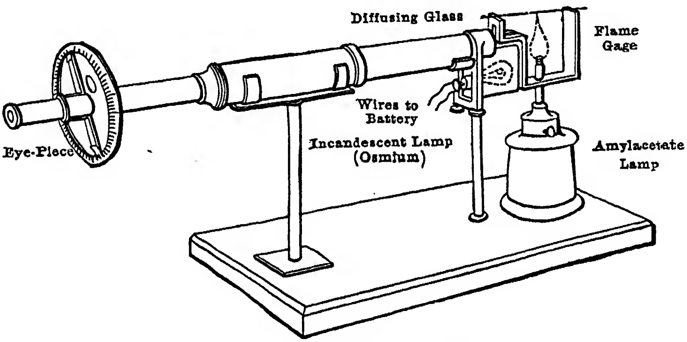


FIG. 164.—Optical pyrometer.

In order to use this instrument, known as Wanner's, the incandescent (osmium-filament) lamp must first be standardized by comparison with an amyl acetate oil lamp of constant candle power. Then after standardizing, it is necessary only to focus the instrument upon the hot body to be measured and the temperature is read directly on the graduated scale at the eyepiece.

Temperature readings from optical pyrometers are actual and are not differences depending on the temperature of the room.

Furnace temperatures may be determined approximately from the values corresponding to the color of the fire. All temperatures are in degrees Fahrenheit.

Red—just visible	900	Orange	2,000
Dull red	1,250	White	2,350
Cherry red	1,600	Dazzling white	2,700

Radiation and optical pyrometers are invaluable for determining the temperatures of the various parts of a furnace, of the walls of the setting of a steam or hot-water boiler, of various portions of a hot bed of coal, etc. It is sometimes stated that an *optical* pyrometer is a means for measuring temperatures of objects "miles away."

Calorimetric Pyrometers.—If the specific heat and weight of a body are known, its temperature can be obtained by observing the rise in temperature of a known quantity of water into which the body is thrown.

More in detail, the method consists in the determination of temperature by putting a ball of metal or of a refractory material into the medium of which the temperature is to be measured. When the ball has become heated uniformly throughout its mass to the temperature of the medium, it is transferred quickly to a cup heavily jacketed with nonconducting material in which there is a known weight of water at a known temperature. Copper, wrought iron, and fire clay are suitable materials. Specific heats of these materials at about 500°F., are, respectively, 0.097, 0.110, and 0.180. Since metals are attacked by furnace gases, they should be protected when used in this way, in a crucible of refractory material.

This method, although not recommended for special tests, is often very serviceable in places or at times when accurate pyrometers are not available. On account of the "personal" error liable to enter, such determinations should be repeated several times to check the results. Calculations required are as follows:

Let w_1 = weight of the ball, pounds.
w_2 = weight of the cup (only the "inner" vessel), pounds.
w_3 = weight of the water in the cup, pounds.
t_1 = initial temperature of water, degrees Fahrenheit.
t_2 = final temperature of the water, degrees Fahrenheit.
t_0 = temperature of the heated ball, degrees Fahrenheit.
s_1 = specific heat of the ball.
s_2 = specific heat of the cup.

Then

$$t_0 = \frac{(w_2s_2 + w_3)(t_2 - t_1)}{w_1s_1} + t_2.$$

Pyrometer Cones.—For many purposes when a pyrometer cannot be well placed, fusible pyrometer cones are used. Such cones are made of ceramic material mixed so as to give a definitely known melting point for each one. The melting points range from 1120° to 3650°F. by irregularly unequal steps, each having a standard number. These cones are carefully graded, so that, if one has had some experience with them, temperatures can be estimated to about the nearest 15° to 20°F. Four of these cones, each in a different condition of fusion, are shown in Fig. 165.

When a series of cones is placed in a furnace, the one having the lowest melting point begins to turn over first. The temperature corresponding to the cone number is reached when the tip of the cone has bent over and just touches the mounting "pat" on which it is standing. Hence the highest temperature reached when the cones shown in the illustration were used was about halfway between that corresponding to each of the two middle cones. According to the numbers on the cones as shown in the figure, the temperature, as given by Table XVIA, was between 1526° and 1580°F. The greatest disadvantage with this system is that there is no way of observing a decrease in the temperature, or, in other words, only the maximum temperature is indicated.

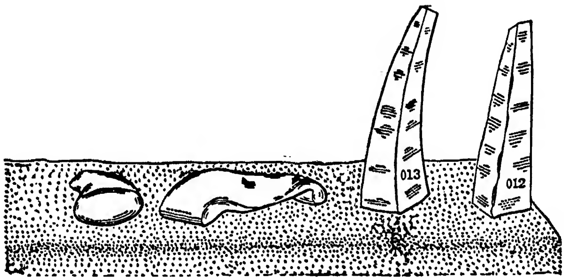


Fig. 165.—Pyrometer cones.

For regulating the temperature in kilns used for making refractory products such as brick, fire clay, or high-temperature furnace mortar, carefully graded pyrometer cones may be used and fairly accurate temperature determinations may be made. In order to determine temperature with these cones, a series laid out to include the approximate temperature to be measured is set in the place where the test temperature is desired. When such a

set of cones is heated, they melt one after another, either completely or partly, and the required temperature is that corresponding to the number (in the table) of the pyrometer cone of which the tip just touches the mounting pat on a level with the base of the cone.

Pyrometer cones do not fuse sharply but soften over a temperature range having a beginning and an end point. The end point is reached just before a cone is fused. In this country the pyrometer cones made for Professor Orton by the Standard Pyrometer Cone Company, Columbus, Ohio, are generally used. Table XVI*A* gives the end points for Orton's standard pyrometric cones.

TABLE XVI*A*.—END POINTS OF ORTON CONES

Cone No.	End point, degrees Fahrenheit	Cone No.	End point, degrees Fahrenheit	Cone No.	End point, degrees Fahrenheit
022	1121	02	2057	19	2768
021	1139	01	2093	20	2786
020	1202	1	2120	23*	2876
019	1220	2	2129	26	2903
018	1328	3	2138	27	2921
017	1418	4	2174	28	2939
016	1463	5	2201	29	2984
015	1481	6	2246	30	3002
014	1526	7	2282	31	3056
013	1580	8	2300	32	3092
012	1607	9	2345	33	3173
011	1661	10	2381	34	3200
010	1643†	11	2417	35	3245
09	1706	12	2435	36	3290
08	1742	13	2462	37	3308
07	1814	14	2552	38	3335
06	1859	15	2615	39	3389
05	1904	16	2669	40	3425
04	1940	17	2687	41	3578
03	2039	18	2714	42	3659

*Cones 21, 22, 24, and 25 are not available.
†There is a negative increment between cones 011 and 010.

Precautions in the Use of Pyrometer Cones.—For maximum accuracy the Orton cones should be set on mounting pats of refractory material of a composition that will not affect the end points of the cones. A suitable material for making these pats

is finely ground alundum mixed with Norton No. 518 cement, using in the mixing as little water as possible. The pyrometer cones should be mounted with the base embedded ⅛ inch in the pat and the face of one side inclined at an angle of about 80 degrees to the horizontal. The pat is usually circular about 2¼ inches in diameter and at least ½ inch thick. The cones may be attached to the pat with the same kind of cement that is used for making the pat.

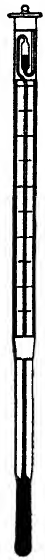


Fig. 166.—Beckman differential thermometer.

Differential Mercury Thermometers. Figure 166 represents a *Beckman* differential thermometer, which is unique in that its range can be shifted by displacing part of the mercury into a reservoir at the top. This is used in calorimeters where a thermometer of short range and one that is capable of being read to a small fraction of a degree is required. By the use of a low-power telescope it is possible to read these thermometers to 0.001°C. Thermometers of this type have a large time lag, and it is necessary to make allowance for this in some cases. The range of the thermometer may be adjusted as required. The length of the scale is generally equivalent to 5°C. and is then numbered from 0 to 5.

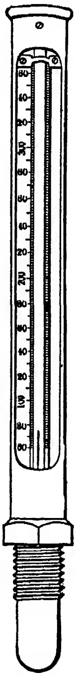


Fig. 167.—Armored thermometer.

Armored Thermometers.—Two types of mercury thermometers protected by heavy metal cases are illustrated in Figs. 167 and 168. These are sometimes called armored *industrial* thermometers. It will be observed that a threaded thermometer well is a part of the casing. The one shown in Fig. 168 has graduations for reading both temperatures and pressures. A thermometer of this type is particularly useful in pipes carrying very hot water. When the temperature is above 212°F., the thermometer will indicate that the water is being heated at a pressure higher than atmospheric.

Precautions for Accuracy in Temperature Measurements.—Before inserting a thermometer or pyrometer in the place where

it is to be used for temperature determination, the following precautions as given by the Power Test Committee of the American Society of Mechanical Engineers should be observed:

1. For accurate results with a thermometer, it should be entirely immersed and the surface of the well through which the thermometer extends should not be abnormally heated or cooled. The use of excessively long emergent stems of thermometers should be avoided. In steam lines the thermometer should not be near heavy pipe flanges that are not well insulated.

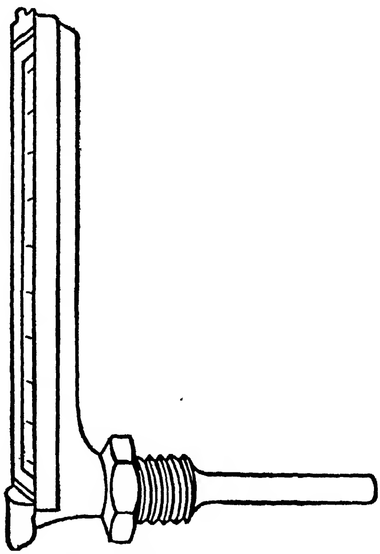


FIG. 168.—Angle-stem armored thermometer.

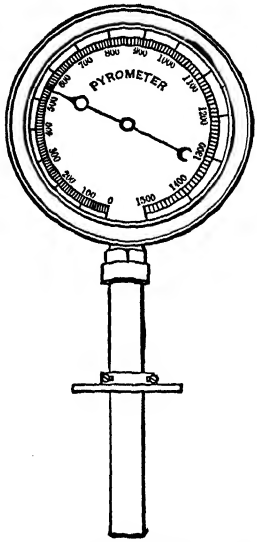


FIG. 169.—Bimetal pyrometer.

2. Emergent-stem corrections cannot be accurately calculated and safely applied to temperature readings from armored industrial (page 241) thermometers. The emergent-stem corrections should be obtained by the comparison method (page 232) with bare thermometers.

3. If the top of the liquid thread in the capillary tube of a thermometer has separated itself from the main thread which extends into the bulb, a correction can be subtracted by estimating the length of the separating space in degrees of the thermometer calibration; and this amount must be subtracted from all the thermometer readings taken at the top of the mercury thread in order to obtain the correct reading for temperature.

4. Electric lights that will not be turned off between readings should not be placed near the stem of a thermometer, if the heat from the lamp is an appreciable amount. This precaution is especially necessary when measur-

ing relatively low temperatures, as, for example, near or below the freezing point of water.

5. Avoid parallax in reading thermometers.

Alcohol Thermometers.—For the measurement of temperatures much below zero Fahrenheit, thermometers filled with mercury are not satisfactory, and alcohol or "spirits of wine" is used. These liquids, on the other hand, are not suited, on account of their vaporizing tendencies for use at high temperatures.

Bimetal or mechanical pyrometers (Fig. 169) consist essentially of two rods made of metals having different rates of expansion which are connected by gears and levers so as to rotate a pointer on a graduated dial. Generally the rods are made of iron and brass or of graphite and iron. Such instruments are usually very unreliable and should never be used for temperatures above 1000°F. There is always a tendency for the zero of the instrument to get higher with use. Beckert and Weinhold found that in a number of cases the zero changed from 200° to 400°F. in two months. In order to obtain readings corresponding to the graduations, the entire length of the tube enclosing the rods should be placed in the chamber in which the temperature is being measured. The Power Test Committee of the American Society of Mechanical Engineers disapproves of their use. Temperature ranges and error limits of thermometer types are given in Table XVII.

Temperature by Color Comparison.—In practical work it is frequently necessary to estimate firepot temperatures of oil burners when no high-temperature instruments are available. Rough temperature determinations may in such cases be obtained by observing the color of a steel rod when held in the part of the firepot in which the temperature is desired. Table XVIII gives the correspondence of the color of heated steel with temperatures and similarly Table XIX gives the approximate temperatures for flame colors.

Heat Units.—Quantities of heat energy are expressed in terms of a compound unit which depends for its value on the product of the weight of water at standard temperature and a temperature difference. The heat unit in most general use is the *British thermal unit* (see page 19).

The *calorie* is the name given to the heat unit in the metric system. A *small calorie* is the amount of heat required to raise

the temperature of 1 gram of water 1°C.; and similarly a *large calorie* is the heat required to raise a kilogram (1,000 grams) of water 1°C.

TABLE XVII.—TEMPERATURE RANGE AND ERROR LIMITS OF THERMOMETER TYPES

Type	Temperature range, degrees Fahrenheit	Limits of error, degrees Fahrenheit
Thermocouple pyrometers:		
(*a*) Base metal.........	300 to 2000	2 to 20
(*b*) Rare metal.	300 to 2800	Limits of error depend on indicating instrument
Electrical-resistance thermometers...	−300 to 1800	0.005 to 5 Depend on indicating instrument
Liquid-in-glass thermometers:		
(*a*) Ordinary glass, mercury-filled...	−35 to 750	0.5 to 7
(*b*) Corning or Jena glass and nitrogen-filled..................	−35 to 925	0.5 to 7
Bourdon-tube thermometers:		
(*a*) Liquid-filled type:		
Alcohol-filled................	−50 to 300	2 to 10
Mercury-filled...............	−38 to 1000	2 to 10
(*b*) Vapor-pressure type:		
Alcohol-filled................	200 to 400	2 to 10
Ether-filled..................	100 to 300	2 to 10
Sulphur dioxide-filled........	20 to 250	2 to 10
Aniline-filled................	400 to 700	2 to 10
Methyl ether-filled...........	−20 to 200	2 to 10
(*c*) Gas-filled type:		
Nitrogen-filled...............	−60 to 1000	2 to 10
Radiation pyrometers...............	Over 1000	20 to 30 for black-body conditions
Optical pyrometers..................	1500 and up	15 to 35
Pyrometer cones....................	1100 to 3600	About 15 to 30 in best makes

Heat-transfer Methods.—According to accepted definitions, heat may be transferred in three ways, singly or in combination; these ways are (1) radiation, (2) conduction, (3) convection.

Radiation (*Radiant Heat*).—All forms of matter are considered to be composed of particles called *molecules*, which are subdivided into *atoms*. Each atom is still further divided into *electrons* which are in constant vibration at the rate of the velocity of light (186,000 miles per second). When atoms collide, some electrons may be knocked off and the *free electrons* of radio transmission are

TABLE XVIII.—TEMPERATURE OF COLORS FOR STEEL

Color	Temperature, °F.
Light yellow	440
Straw yellow	460
Dark yellow	480
Brownish yellow	500
Light purple	520
Dark purple	540
Dark blue	570
Very dark blue	600

TABLE XIX.—TEMPERATURE SCALE FOR OIL-BURNER FLAMES

Color	Temperature, °F.
Red visible in dark	750
Red visible in daylight	950
Blood red	1050
Dark cherry red	1150
Medium cherry red	1250
Full cherry red	1350
Bright cherry red	1500
Orange	1650
Light orange	1750
Yellow	1850
Light yellow	2000
White	2200

obtained. The vibrations of the electrons for heat, light, and radio transmission differ only in wavelength, the heat waves being longer than those for light or radio transmission.

Simply stated, radiation or radiant heat is merely a wave motion, which is a form of light of relatively long wavelength that travels out from its source as vibrating waves.

All forms of matter are continually radiating and absorbing radiation, but the rate of this energy transfer depends on the kind of surface, especially as to roughness and color, of the materials concerned and the temperature difference* between them.

* Theoretically, it is the difference of the fourth powers of the temperatures.

Conduction.—Heat will flow from one substance to another when in contact, or from one part of a substance to another in the direction from the higher to the lower temperature. This heat transfer of heat *through contact substances* or *through a substance* (Fig. 170) is called *conduction.* For example, the heating of the silver handle of a steel knife when the steel blade is held in the flame of an oil burner is an example of heat conduction.

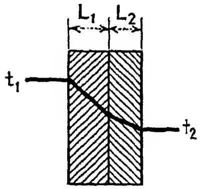


FIG. 170.—Heat resistances in series.

The rate at which heat is conducted is called the *conductivity* of the substance. A substance which conducts heat within itself rapidly is called a *good heat conductor,* and substances that retard heat transfer are *heat insulators* (page 294).

In cases where two materials *in contact* are conducting heat it is necessary to determine the heat conductivity of each material. If Q is the *total* heat transmission in B.t.u. per hour, then

$$Q = \frac{t_1 - t_2}{\dfrac{L_1}{K_1A_1} + \dfrac{L_2}{K_2A_2}} \tag{22}$$

where t_1 = surface temperature on warm side, degrees Fahrenheit.
t_2 = surface temperature on cold side, degrees Fahrenheit.
K_1 = coefficient of heat conductivity of one material.
K_2 = coefficient of heat conductivity of other material.
L_1 = length of heat path in material with K_1 coefficient.
L_2 = length of heat path in material with K_2 coefficient.
A_1 = area of material section with K_1 coefficient.
A_2 = area of material section with K_2 coefficient.

Usually, $A_1 = A_2 = A$, then

$$Q' = \frac{(t_1 - t_2)A}{\dfrac{L_1}{K_1} + \dfrac{L_2}{K_2}} \tag{23}$$

Also if the subscript 3 is used to apply to a third material, all three materials being in contact and $A_1 = A_2 = A_3 = A$,

$$Q'' = \frac{(t_1 - t_3)A}{\dfrac{L_1}{K_1} + \dfrac{L_2}{K_2} + \dfrac{L_3}{K_3}} \tag{24}$$

A more complicated case is shown in Fig. 171. In this example, the *conductance* must be calculated by using the values of heat conductivity for the various building materials shown.

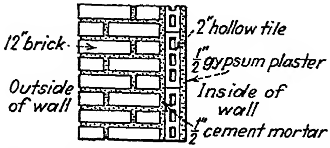


FIG. 171.—Heat resistances in a building wall.

Convection.—Heat transfer *within* a liquid, a vapor, or a gas from one point to another is convection, which may be either *natural* or *forced*. Natural convection takes place when water is heated as in a steam boiler. Another example is the flow of air in a warm-air heating plant.

CHAPTER VIII

CALCULATION OF HEATING SYSTEMS*

Methods of Heating.—For the heating of a building, large or small, it is necessary, first, to burn fuel which may be a solid, a liquid, or a gas. This burning or combustion of the fuel may take place in a fireplace, a stove, or on a grate of the kind provided in a warm-air furnace or in a steam or a hot-water boiler.

The simplest type of heating device is the stove, from which the heat produced by fuel combustion is diffused into a room by radiation and convection directly to the surrounding air. Before the invention of stoves, fireplaces were the principal means used for the heating of buildings. Although the introduction of stove heating reduced a great deal the use of fireplaces, they have continued in considerable demand even to the present time, when they are used mainly as a supplementary means of heating individual rooms.

Although a stove has a small grate, it is not generally thought of as a typical example of the use of "grate" combustion, which is usually associated with burning of fuels in warm-air furnaces and boilers.

In the warm-air heater, the heat developed by the combustion of fuel on the grate is transmitted mainly by radiation (page 245) to the so-called *heating surfaces* in the heater. When a warm-air heater is the heating appliance, the rooms in a house are heated to a comfortable warmth by the circulation in them of warm air from this heater. This warm air is usually carried to the various rooms in the house through circular pipes or rectangular ducts. By this method there is a constant circulation of air, a part of which may be fresh air from outside the building. The admission of fresh air in extremely cold weather adds a great deal to the amount and cost of fuel that must be burned. Obviously,

* This chapter is not restricted to the heating systems of residences only as the automatic types of oil burners are being installed successfully in batteries, each including a large number of units as illustrated in Fig. 172.

a larger amount of heat is required to warm fresh air from the "outside" temperature up to the required temperature of the rooms than for merely heating the air in the various rooms of a house by some other method which does not depend on the circulation of fresh air. The fresh air that is taken into the warm-air heater and passed over the heated surfaces above the fuel bed serves to replace the heated air that is lost from the several rooms by air leakage through the cracks in windows, doors and sometimes in walls.*

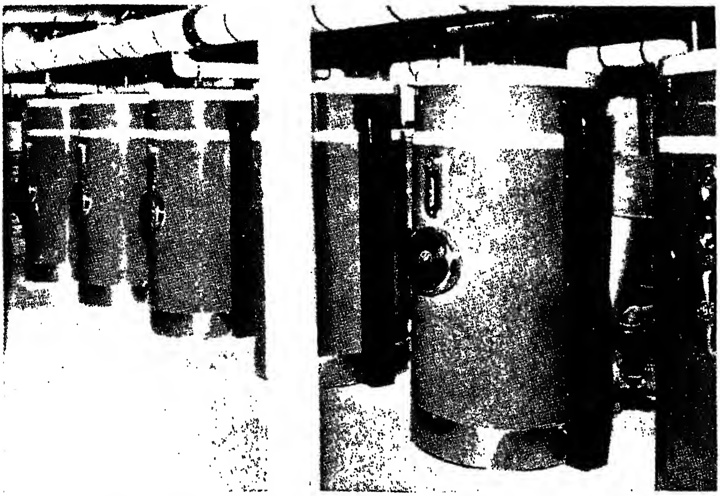


FIG. 172.—Battery of automatic-burner boilers for group heating.

A building located in a place where it is directly exposed to cold winds, especially to those with north and west exposures, is more than ordinarily difficult to heat comfortably. Heating difficulties caused by an exposed location may be overcome to some extent by the skilful and studied placing of the warm-air heater, and by the use of slightly larger pipes and ducts than would otherwise be specified for carrying the heated air to the rooms that have walls exposed to these north and west winds.

Direct-steam-heating System.—A method of heating the rooms of a building by the heat obtained from radiators or coils of pipe

* The recirculated air should not include any drawn from kitchens or lavatories. Such rooms should have direct outside vents, with exhaust fans provided for air discharge from kitchens.

through which steam circulates at a temperature somewhat higher than that of boiling water at atmospheric pressure is called the "direct-steam" or "direct-radiation" system. This system of heating is very commonly used in all kinds of buildings, where this system may be used exclusively, or where it may be installed in combination with some other system. The first cost of this system including installation is greater than for a warm-air heater and its installation, including ducts and registers (page 297); but the cost of operation may be less for the reason that less fuel is required in a system of this kind in which no outside air supply is required for its operation, than for a method usually requiring in cold weather the heating of some air taken in from the outside. The principal advantage of the direct-steam or direct-radiation system of house heating over warm-air systems (page 291), is, however, that all the rooms may be heated day after day to approximately the same temperature without regard to the direction from which the wind comes. In the application of the direct-steam or direct-radiation method, the sizes of radiators should be selected according to the heating requirements of the rooms in the coldest weather. With this method there is no satisfactory device for regulating the *amount* of room heat in *mild* weather, except by shutting off or turning on the steam in the radiators at more or less frequent intervals as may be required, unless a system of automatic temperature control (page 139) is used. In relatively large rooms some adjustment by hand is possible with this method of room heating by installing more than one radiator for heating, so that one, two, three, or more radiators can be used for the varying conditions of outside temperature. Some engineers recommend that in such a division of heating surface in a room, it should be proportioned in the ratio of, say, one to two, meaning that one of the radiators would be twice as large as the other. Then, with heating surfaces arranged in this way, one-third, two-thirds or the total amount of direct steam or direct-radiation surface can be used.

Indirect-steam-heating System.—A method of heating the rooms of a building which combines some of the advantages of both the warm-air-heater system and direct-steam-heating system (direct radiation) is called indirect-steam-heating or indirect-radiation system. In the application of this method, the

radiators may be simply fin-type coils* grouped in a special form of heating compartment, generally supported from the ceiling in the basement where they are covered by a casing usually made of galvanized iron. In other words, in the application of this system, the radiators or coils used for heating are all placed as a unit in some part of the basement or cellar of the building instead of being placed in the individual rooms as in the direct-steam-heating or direct-radiation system. A cold-air-supply duct is in many cases connected into the bottom of the box containing the heater coil, and warm-air pipes or ducts set into the top of the box are connected with registers (page 297) in the various rooms in the house in very much the same way as the registers are located in the method of heating with a warm-air heater. A separate heater coil similar to a unit heater (page 289) may be provided in large rooms for each duct leading to a register, but if the rooms are small, a single heater coil may serve two or more rooms, and in the case of a house with few rooms a single heater may be adequate for all the rooms.

An indirect-steam (or indirect-radiation) system may be constructed so that it will supply more fresh air than with the ordinary type of warm-air heater. In any case, the cost of fuel for the indirect system is certainly likely to be greater than that for the direct-steam system, and depending on the volume of fresh air admitted may be proportionally larger than even the cost of fuel for a warm-air-heater system. The principal advantage of an indirect system over the warm-air-heater system is that the ducts for supplying the registers in the various rooms may start in the basement immediately below the registers in the several rooms, with the radiators or heater coils placed in boxes supported from the basement ceiling. In this way, unsightly and inconveniently long horizontal ducts from the heater to the side-walls of the building can be avoided in the basement. This method has also the advantage of preventing to a considerable extent the effect of the direction of the wind on the heat distribution to the various rooms.

Indirect- and direct-heating systems are often combined advantageously by the use of the former system for the more important

* Cast-iron radiators with outer-surface fins (page 256) are frequently used in indirect-heating systems.

rooms in the house where ventilation is especially needed and the latter system for the rooms that do not, as a rule, have much occupancy.

The method of distributing the warmed air by a positive (fan) circulation to the various rooms in the house by the indirect method makes it possible to distribute air at a much lower temperature than is possible with the relatively small heating surface that is available in a warm-air heater as they are usually supplied for the heating of buildings. This lower temperature of the heated air with consequently larger volume distribution makes the rooms more comfortable than they are when a smaller volume of air is discharged from the registers, at a much higher temperature, as is the case when the heated air comes from a warm-air heater. The air distributed by the indirect system may be more comfortable in still another way for the occupants of rooms, because the relative moisture in the warmed air, called the humidity (page 355) can be more readily and satisfactorily controlled, unless an adequate, controlled, and expensive humidification system is provided for operation with the warm-air heater and its heating equipment.

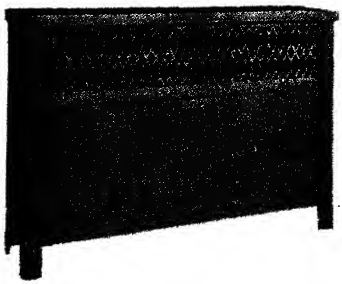


FIG. 173.—Casing for enclosing steam or hot-water radiator.

Direct-indirect-heating System.—A system of room heating, which is only a modification of direct-steam (or direct-radiation) system, in which radiators are located in the usual way on the floor of the room to be heated, and each radiator is enclosed in a sheet-metal box or casing which has a small flue at the bottom that extends through the wall of the building so that outside air can enter the room, is shown in Fig. 173. From this casing, after being heated by the radiator, the air is discharged into the room through a grille in the front or the top of the casing. A damper is usually placed in the fresh-air flue at the base of the radiator, so that the amount of outside air to be taken to the radiator through the flue can be regulated. This method of heating has the disadvantage that there is likely to be a considerable leakage of cold

air into the room around the flue passing to the outside; and usually this leakage is difficult to prevent. The method is, however, especially suited to the case of a room in a relatively remote part of a house which is difficult to ventilate, providing in that case a flue is constructed in the wall of the house to reach from the basement to the room.

Direct-hot-water-heating System.—In this method of heating, hot water is circulated through pipes and radiators instead of steam. It has the advantage that the temperature of hot water is easily changed and regulated, while the temperature of steam similarly circulated is capable of very little adjustment, the temperature being usually about 215°F. Therefore, when steam is used in direct heating (or the so-called "direct radiation") the radiators of the types commonly used are always at practically the same temperatures. On the other hand, when the same radiators are heated with circulating hot water, the temperature of the water can be readily varied from the temperature of the water supply up to about 175°F.

A hot-water-heating system is more expensive, however, in total cost of installation than a direct-steam system, as the radiators and the connecting pipes from the heater to the radiators must be much larger than the pipes and radiators for a direct-steam system. The fuel cost, however, for a direct-hot-water system for maintaining the same temperatures in rooms is somewhat less for hot water than for steam, because the circulating hot water may be at a much lower temperature than that of steam at atmospheric pressure in mild weather, while in cold weather, the temperature may be raised to such an extent that it will be at a temperature of only about 40°F. less than the temperature of low-pressure steam. When a special type of steam system is operated with a vacuum in the return pipes (as explained on page 270), the steam system can be regulated as effectively as a hot-water system. In this connection, it is also important to have in mind the greater comfort that is obtained with the hot-water system in comparison with a steam system operated at atmospheric pressure or above. In mild weather, the hot-water system can be carried at a temperature which is just high enough to warm the room properly, while with the ordinary steam system,* the

* The ordinary direct-steam-heating system referred to here does not have thermostatic control of temperatures (p. 158).

rooms are apt to be overheated, and during mild weather heat is sometimes wasted by the opening of doors and windows.

There is, however, an important disadvantage of the hot-water system in comparison with any steam system, and that is that there is a danger that the water in the radiators will be frozen when the heat is shut off in unused rooms in severely cold weather. On this account, it is necessary in very cold weather to have all the radiators in a hot-water system turned on sufficiently to obtain at least a slow circulation of the water. A precautionary device for avoiding this trouble is made by drilling a small hole, about ⅛ inch in diameter, in the valve seat of each radiator valve, so that there will be some circulation at all times through this small opening. This device, of course, is especially useful during freezing weather. Another disadvantage is that a much longer heating-up period is needed for hot-water than for steam heating. The application of a small circulating pump usually located in the water-return pipe to the boiler assists a great deal in obtaining quick heating-up in a hot-water system. The pump is usually operated by an electric motor controlled by the same temperature-control device (page 176) that operates the oil burner in the boiler, so that the pump operates only when the burner does.

Indirect-hot-water-heating Systems.—If a heating system is designed for the use of hot water in an indirect way, it corresponds, in all essentials, to the indirect method of steam heating (page 250). The two systems are more nearly alike, however, as applied in private residences than in larger buildings where it is customary to provide a positive circulation of the hot water through the various rooms by means of a pump rather than depend on gravity circulation as is done usually in private houses. The arrangement of air flues and registers is practically the same for indirect-hot-water heating as for indirect-steam heating. The cost of the boiler, piping, and heaters in the ducts is greater, however, for the indirect-hot-water system than for the indirect-steam system for the same reasons that a direct-steam-radiation system is cheaper than a direct-hot-water-heating system (page 253).

Types of Radiators.—In every room heated by a direct-steam or hot-water-heating system, it is necessary to have one or more efficient heating units. These heating units are called "radi-

ators." The ingenuity of the designer of a heating system is always taxed to find the best arrangement of heating surfaces, that is, the best location and selection of radiators for each individual room. If the radiators in a room are too small, it will be impossible, of course, in cold weather to warm that room adequately, and if they are too large, there is unnecessary cost in the installation of the heating system, and there will be complaints because some rooms are overheated when others are comfortable

The principal types of radiators are the following: (1) direct-heating radiators; (2) indirect-heating radiators; (3) concealed radiators; (4) direct-indirect radiators; (5) built-in radiators.

These radiators are composed of several sections, the number of sections used depending on the amount of heat-radiation surface that is required. The sections are made in several different widths and heights. The wider sections are divided through most of their lengths by vertical slots into 2, 3, or more columns (for column-type radiators), and tubes (for tube-type radiators).

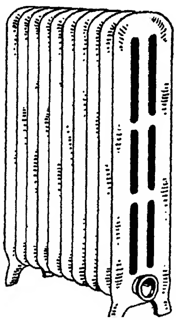


FIG. 174*a*.—Column-type radiator.

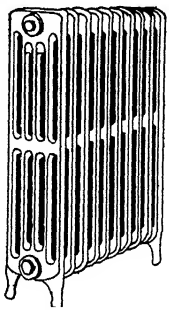


FIG. 174*b*.—Tube-type radiator.

Direct-heating radiators are placed in the room to be heated, usually on the floor.

Indirect-heating radiators are placed in some other room or space than the room to be heated. They deliver a flow of heated air usually through openings in the floor or walls of the room in which registers (page 297) are placed.

Concealed radiators are placed in concealed locations, usually in nooks in the walls of the room, where they are largely hidden by grilles or other ornamental iron covers.

Direct-indirect heating radiators are set up in the room without much concealment. They are located in places in the outside walls where there are openings intended for the admission of outside air. Ventilation, of course, is one of the principal objectives when this type of radiator is installed.

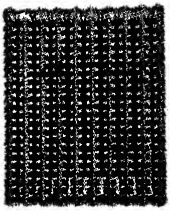


FIG. 174c.—Vento cast-iron radiator.

Built-in radiators are built into walls or partitions of rooms and emit heat almost entirely by convection (page 247).

Formerly the *column* type of radiator (Fig. 174*a*) was in general use, but now the *tube* type (Fig. 174*b*) is commonly used, as well as also the *vento type* (Figs. 174*c* and *d*), and the *pin type* (Fig. 174*e*).

Where radiator space is at a premium, the tubular type made of *seamless copper tubing* with "fins" in different forms is used. The "fins" are arranged on the tubular sections to provide a maximum of heating surface.

FIG. 174*d*. Single section of cast-iron vento radiator.

The sections of either the column-type or the tube-type radiator are joined together by tightly fitting nipples and bolts which extend through the full length of the radiator to force these nipple joints to a tight fit. Direct-heating radiators are also frequently constructed in the wall type. A radiator of this kind is commonly used in places where it must be hung from the ceiling by brackets or where there is a great deal of unused wall space and a minimum of floor space. Direct-heating radiators made of cast iron are usually subjected to a *hydraulic-pressure test* in the factory of 120 pounds per square inch. This pressure is, of course, much higher than that to which the radiators will ever be subjected in a small building, although the pressures to which hot-water radiators are subjected in tall buildings sometimes approaches this figure. The weight of cast-iron radiators per square foot of heating surface (manufacturers' rating) is usually about 5½ pounds.

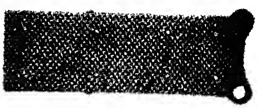


FIG. 174e.—Pin-type radiator.

Thermostatic Traps.—An essential feature of two-pipe systems* of steam heating is the steam trap which must be of the thermostatic kind so that it will be automatic. A manually operated valve at the outlet of a radiator used in a vapor system (page 263) would, for practical reasons, make the radiator inoperative most of the time. Some commercial designs of thermostatic traps are shown in Figs. 175*a* to 178. Each of the designs shown in the figures depends for automatic operation on the expansion of a volatile liquid which is usually alcohol or kerosene. In all the designs shown, except Fig. 178, the volatile liquid is contained in a thin-walled metal chamber of which at least one side is sufficiently flexible to cause, by the application of pressure within, a movement of considerable magnitude of the flexible side of the chamber. The volatile liquid used in the thin-walled chamber must have the property that it will volatilize at a temperature somewhat below 210°F. Thus, any heating above this temperature will produce sufficient pressure to expand the thin-walled chamber to such an extent that a flexible side will cause a movement of sufficient magnitude to close automatically the discharge valve of the trap. The method of operation of traps of this kind is shown clearly by the sectional views of traps illustrated. In Fig. 175*a* the thin-walled chamber *C*, when expanded by the presence of a hot liquid surrounding it in the chamber *M*, will press the disk *V* downward upon the valve seat *S*, thus shutting off the outward flow of any liquid that may be in the pipe *P* or in the passage *M*. A slightly

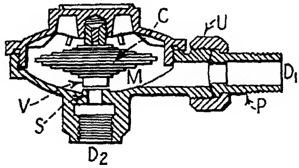


FIG. 175*a*.—Thermostatic with flexible horizontal on valve stem.

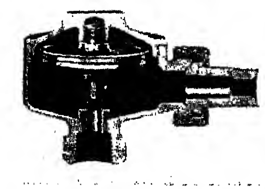


FIG. 175*b*.—Thermostatic trap similar to Fig. 175*a*.

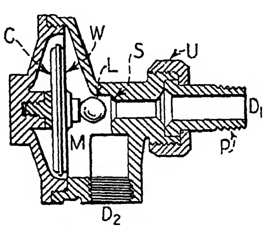


FIG. 176.—Thermostatic trap with flexible vertical disk (ball operated).

* Thermostatic traps are needed in any two-pipe system of steam heating, unless there are orifices at the inlet valves of each radiator.

different design but operated by the same principle is illustrated in Fig. 175*b*. Similarly, in Fig. 176, the expansion of the flexible wall *W* of the thin-walled chamber *C* will force the ball *L* upon the seat *S* of the trap so that the discharge of liquid and air through the pipe *P* is prevented. Similarly, in Fig. 177 the expansion of the thin-walled bellows *B* forces the cone *N*, which is on a downward projecting spindle, upon the valve seat *S*, and thus shuts off any discharge from the passage *M* that enters through the pipe *P*. The seat of the cone *N* is kept in a central position by a rod or stem *T* of small diameter. In each of the cases illustrated, the thin-walled chamber *C* or the bellows *B* is filled with the volatile liquid, which by its expansion will close the discharge valve of the trap.

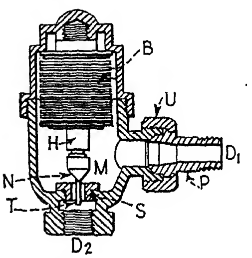


FIG. 177.—Thermostatic trap with expanding bellows attached to valve stem.

In the actual operation of such thermostatic traps, the discharge valve of the trap remains open only long enough to allow the air and the condensed steam (condensation) to pass out from the radiator. When the steam begins to accumulate as walled chamber *C* containing the volatile liquid becomes heated nearly to the steam temperature and the expansion of the volatile liquid moves its flexible wall and thus closes the valve controlling the discharge from the trap. This discharge valve then remains closed until there is a sufficient accumulation of condensed steam in the radiator and in the passage *M* of the trap to cool sufficiently the thin-walled expansion chamber *C* so that by its contraction it will again open the valve for the discharge of air and relatively cool condensed steam. However, when after the emptying of condensed steam and air, steam again enters the discharge pipe *P* of the radiator and fills the passage *M*, the thin-walled expansion chamber *C* will again close the discharge valve of the trap.

A thermostatic trap which depends for its operation on the expansion of a U-shaped tube is shown in Fig. 178. In this type, the operating member is a specially constructed *Bourdon tube* (page 234), operating on the same principle as the usual type of pressure gage actuated by the Bourdon-tube method. The tube is charged with a volatile fluid and is hermetically sealed. The expansion and contraction of the volatile fluid under various tem-

peratures is the means applied for opening and closing the conical-shaped valve. The Bourdon tube is mounted vertically so as to give a horizontal valve motion. The right-hand end of the U-shaped tube is securely fastened to the wall of the trap so that the back-and-forth travel of the tube either opens or closes the valve. The expansion of the tube which occurs when it is heated closes the valve against the flow of steam.

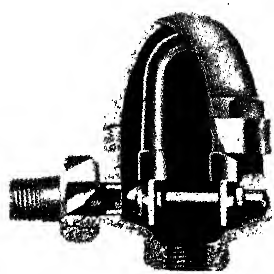


FIG. 178.—Thermostatic trap with horseshoe Bourdon tube.

Another type of radiator trap is the kind that has its discharge valve operated by a float. In this type, the opening and closing of the discharge valve depend entirely upon the flow of condensation into the trap. There is a disadvantage in the use of float traps for use in residences, apartment houses, hotels, and office buildings as they are sometimes so noisy in operation as to be a source of annoyance to the occupants of the rooms in the building. It is also more difficult to prevent leakage from a float-operated trap than from one that is operated thermostatically.

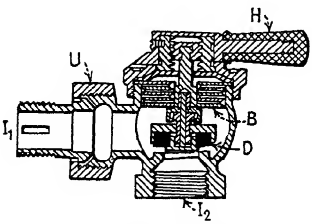


FIG. 179*a*.—Steam radiator-inlet valve with bellows-type packing.

In cases where the supply of steam reaching a radiator is so restricted that no more steam can enter the radiator at any time than can be condensed, and consequently, no *steam* can be discharged from the radiator into the return pipe, a trap is not needed. One way to obtain steam restriction, as explained, is to place a disk in which there is a small *orifice* in the inlet pipe of the radiator, as, for example, in the union fitting U in Figs. 179*a* or 179*b*. The valve shown in Fig. 179*c* is intended for hot-water-heating systems, the orifices and baffles being used to secure an even distribution by placing, in the radiators of the heating system, resistances of various sizes as needed.

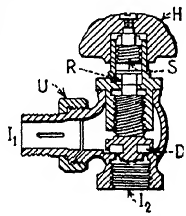


FIG. 179*b*.—Steam radiator-inlet valve with rubber packing.

Air Valves.—For the automatic removal of the air that accumulates in steam radiators *air valves* may be used. A typical valve for this purpose is shown in Fig. 180*a*. It operates by the expansion of a phosphor-bronze diaphragm *D*, soldered on the bottom of a brass float *F*, containing a volatile liquid. This float should have sufficient liquid capacity to develop the necessary pressure to operate the diaphragm.

FIG. 179c.—Hot-water radiator valve with orifice and baffle attachments.

The seating pin *P* at the top of the float should be made of an alloy such as nickel silver on which verdigris will not form. Corrosion at the air vent is therefore reduced to a minimum.

The type of air valve illustrated in Fig. 180*b* operates with the application of a metered orifice disk, with the object of controlling the rate of flow of air from the radiator. Controlled venting is obtained by using any one of six measured positions on the disk.

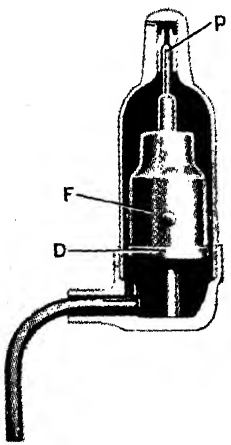


FIG. 180*a*.—Simple-type air valve.

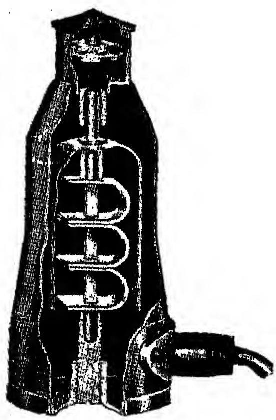


FIG. 180*b*.—Graduated-operating air valve.

In this type of air valve, the minimum opening is 0.045 inch in diameter, and the full opening is 0.096 inch in diameter, making the minimum area of opening only ⅕th as large in area as the

maximum opening. On intermittent heating systems, as, for example, automatically operated oil burners, an air valve of this type has some advantages, as it insures a proportionally equal steam distribution regardless of the size of the radiators in the various rooms and the distances of those radiators from the boiler. With the proper setting, the largest or the most distant and the smallest and nearest radiator will heat up simultaneously.

Single-pipe Systems of Direct Radiation.—The simplest form of a direct-steam-radiation system is shown in Fig. 181*a*. This simple arrangement of direct radiation is commonly called a single-pipe system, but is also sometimes called a "one-pipe" *system*, in order to distinguish it typically from other systems that

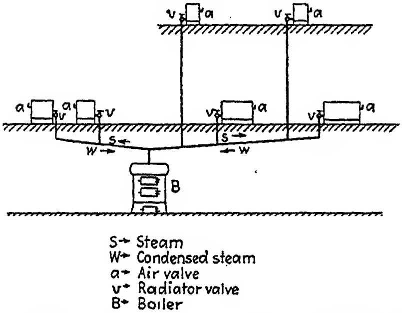


FIG. 181*a*.—Simple single-pipe system of direct radiation with steam mains sloping toward boiler.

have two pipe connections to each radiator (page 255). In the figure, the horizontal pipes at each side of the boiler *B* which carry the steam used for heating from the boiler are called the *steam mains* and the connected vertical pipes shown extending to the upper floors of a building are called *risers*.

Steam generated in the boiler flows through the mains and rises into the radiators, forcing the air out ahead of it through some kind of *air valve* on the end of the radiator opposite the steam-supply connection from the riser. In the figure, the air valves are marked *a* and the radiator-shut-off valves *v*. In the system shown here, the condensed steam formed in the radiators drains down first through the risers and then through the mains, and finally back to the boiler. The flow of the condensed steam, it will be observed, therefore, is opposite in direction to the flow of steam.

So far as the risers are concerned, if the system is in a small building, this is not objectionable. Because the flow of condensed steam (water) and the flow of the "live" steam are in opposite directions, however, they are likely to interfere with each other in the steam mains, unless the mains are made so large that even when a large part of each pipe is conveying water, there will be room enough for the flow of steam at a low velocity. If, however, the steam mains are small, so that such interference takes place, the water is picked up by the steam and is driven to the end of the main where it is likely to produce a loud noise commonly called "water hammer."

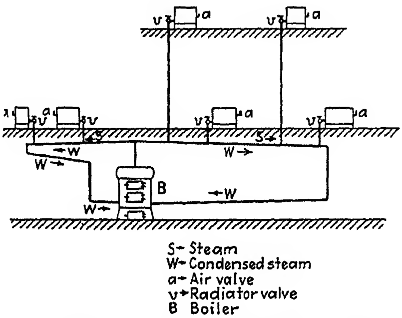


FIG. 181*b*.—Single-pipe system of direct radiation with steam mains sloping away from boiler.

A better design of a single-pipe system of direct radiation is shown in Fig. 181*b*. In this case, the steam mains are inclined away from the horizontal and *from* the boiler, so that the condensation entering the steam mains from the risers flows in the same direction as the live steam on its way to the radiators. The slope of the mains is therefore in the opposite direction from those in the preceding figure. The arrangement shown in Fig. 181*b* is the one commonly used for single-pipe systems. The steam mains are usually laid out to extend at least partly around the walls of the building, and an ordinary drip connection is provided to carry from the farther ends of the piping condensed steam into the boiler at such a level that it enters below the water line (the imaginary average line separating the water space in a boiler from the steam space).

The two arrangements of a single-pipe system are shown here with single-line drawings, which are intended to be simplified

representations of the piping. In an actual piping design, incorporating either of these systems, the layout of the pipes would have to be somewhat different from that shown in these figures, and more like those on pages 266 to 269.

Vapor-heating Systems.—A low-pressure steam-heating system called the vapor system has many desirable features. In fact, it has, in many respects, most of the advantages of the hot-water system, but does not require the relatively large boiler, pipes, and radiators that are needed for that system. In the vapor system, the steam is circulated at a very low pressure, usually only a few ounces per square inch more than atmospheric pressure. The principal other difference between the vapor system and the ordinary steam system is that in the ordinary steam system (direct or indirect), the air that always accumulates in radiators must be forced out of each of them through a very small orifice in an air valve (page 260), and in order to accomplish this discharge of air through the air valve, a steam pressure of at least 1 pound, and in the case of old valves in poor operating condition, several pounds per square inch more than atmospheric pressure is needed. In the vapor system, however, there is practically no resistance to vapor flow, so that a pressure of only a few ounces per square inch more than atmospheric pressure is needed. A diagrammatic representation of *typical* atmospheric steam and air conditions in a radiator operated by the vapor system is shown in Fig. 181*c*. As represented here, the steam enters the radiator R from the vertical pipe P_1, passing through the regulating valve V.

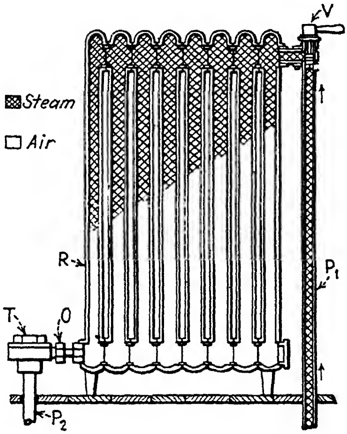


FIG. 181c.—Radiator operated by vapor-heating system.

From this valve, the steam flows outward and downward into the various sections of the radiator, forcing the entrapped air and condensed steam in the radiator through the outlet pipe O, the trap T, and the return pipe P_2. The radiator shown in the figure is, however, only partly filled with steam. The partial

filling may be caused by a limited available steam supply obtainable from the boiler, or it may be caused by the partial closing of the regulating radiator valve V. When, however, a sufficiently large steam supply is available from the boiler and the regulating valve V is wide open, the radiator will be completely filled with steam; but there will be practically no discharge of steam for the reason that the thermostatic trap T (page 257) operates so that it discharges only condensed steam (water) and air and closes automatically its discharge valve when steam enters the trap. The heating surface of that part of the radiator that is filled with steam will, of course, be nearly at the steam temperature. The rest of the heating surface of the radiator is only slightly warmed by the condensed steam (condensation) which trickles down the inside surface of the radiator. Typical vapor-system regulating *radiator-inlet valves* are shown in Figs. 179*a* and 179*b*. As already explained, the admission of steam to the radiator can be controlled by adjusting the amount of opening of the regulating radiator valve so that the radiator may be completely or only partly filled* with steam as may be desired. Although such equipment for the regulation of the heat supply of a vapor-heating system is costly, it has been found in practice that very few people will take the trouble to make such adjustments, and in most cases the regulating valves are either wide open or completely closed. But if it is admitted that the possible advantage of partial filling of the radiator with steam is not usually obtained in the operation of such radiators, there is still to be considered the advantage of the vapor system over the direct- or indirect-steam-heating systems, owing to the fact that because of better circulation, the low-pressure steam in the radiator heats it more quickly than steam at a higher pressure, and the heating effect is more even and continuous than with the other systems of steam heating. These advantages of a low-pressure-steam supply are especially important in connection with the operation of a small steam unit. There is also a convenience advantage in having the steam-regulating valve at the top of the radiator instead of near the bottom as in some systems, and also in having a valve that can be opened or closed all the way with a single turn of the valve handle.

* Partial filling with steam is easier of accomplishment when orifices or baffles like those in Fig. 179c (intended mainly for hot-water radiators) are placed in the union between the inlet valve and the radiator.

The cost of the special types or regulating valves, traps, and fittings that are needed make the vapor system more expensive than some of the simpler types of steam systems. Obviously, because there is a return pipe to the boiler, the vapor system requires two complete lines the same as in any other "two-pipe" system. The leakage of steam around the stem of the valve, shown in Fig. 179*a*, which is at low pressure, is prevented by a flexible bellows *B*. When a bellows of this kind is used around the stem of a valve, steam leakage is effectively prevented, and it is unnecessary to place around the stem a so-called "gland" of soft packing like that commonly used for making an ordinary radiator valve (page 259) steam-tight. Figure 179*b* shows a valve which has a rubber packing ring *R* to prevent leakage around the stem. This packing ring is held in place by the compression of a spiral spring *S*.

One-pipe Vapor-heating System.—Briefly defined, a one-pipe vapor system of steam heating operates at pressures at or near atmospheric, with provision for the return of the condensed steam to the boiler by gravity. The piping arrangement of a one-pipe vapor system is similar to that of a one-pipe direct-steam-heating (or steam-radiation) system. There is so much similarity that, as a rule, it is easily possible to change a one-pipe direct-steam radiation system to a one-pipe vapor system. All vapor systems are intended to operate at a gage* pressure of only a few ounces per square inch.

Two-pipe Vapor-heating System.—In any two-pipe vapor system, one line of piping is intended to carry the steam to the radiators, and the other line to carry off the condensed steam and also air. In other systems than the vapor system, the return line of piping carries very little air, and provision is therefore made by the use of a special device for the removal of air. In a hot-water system, the air is removed through a very simple air valve.

In general practice, there are two kinds of vapor systems that have both a supply line and a return line. Such layouts are called two-pipe vapor systems, and this grouping is subdivided into (1) *closed systems* in which there is a device, usually a check

* *Gage pressure* is greater than atmospheric. It is distinguished from *absolute pressure*, which is measured from an absolute vacuum. Zero gage pressure at sea level is approximately 14.7 pounds per square inch in absolute pressure. See "Elements of Engineering Thermodynamics," 5th ed., p. 3, 1933, John Wiley & Sons, Inc., New York.

valve, to prevent the return of air after it has passed out of the system; and (2) *open systems* in which the return line is constantly open to the atmosphere without a check valve or other equivalent device to prevent the return of air. Both the closed and the open systems will operate at about the same pressure at the radiators, that is, a few ounces per square inch above the atmospheric pressure. The closed two-pipe vapor system is shown diagrammatically in Fig. 182. The distinguishing equipment of this system is that there is a packless graduated plug-cock valve on each radiator, a thermostatically operated trap on

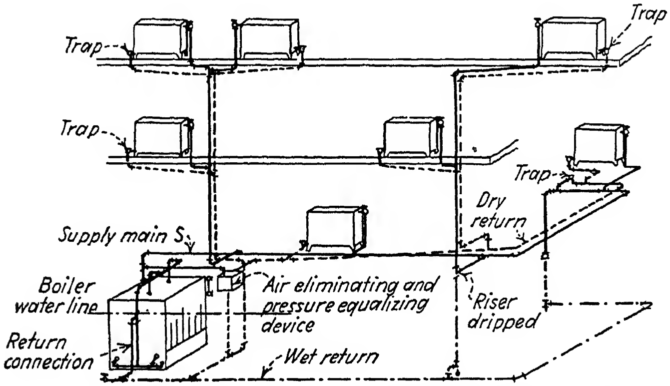


FIG. 182.—Typical upfeed vapor system with automatic return traps. (*From A.S.V.H.E. Guide*, 1936, *Chap.* XXXI.)

the return pipe at the discharge from each radiator, and traps on all drip lines that are not water-sealed. A system like the one shown in the figure should be equipped with an automatic return trap (page 272) to prevent a flow of water out of the boiler. The arrangement shown in the figure is called the "upfeed" type, which means that the steam-supply piping is carried to a high point directly over the boiler and is graded down toward the end or ends of the supply main, each supply main being dripped at the end into the wet return pipe or carried back to a point near the boiler where it will be below the boiler water line and become a wet return line.

From the supply main S in the figure, branch lines are taken off to feed the risers which carry the steam supply to the various floors of the building. The steam-supply lines must be graded toward a steam main, or a drip pipe must be fitted at the bottom

of the riser through which the condensed steam can be carried back to the boiler or discharged into a hot well or similar container for receiving condensation drips. The two methods of condensation removal are shown in Figs. 183*a* and 183*b*. The pipe connection at the bottom of each radiator is connected to

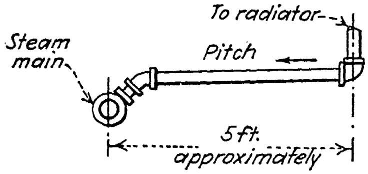


FIG. 183*a*.—Typical steam runout where risers are not dripped. (*From A.S.H.V.E. Guide*, 1936, *Chap.* XXXI.)

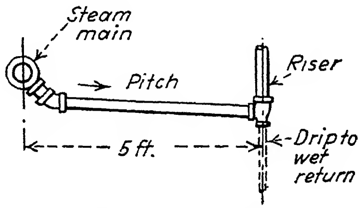


FIG. 183*b*.—Typical steam runout where risers are dripped. (*From A.S.H.V.E. Guide*, 1936, *Chap.* XXXI.)

the return steam main through "runouts" which slope toward the main. The return main, when, as is usually the case, it is located above the boiler, should slope toward the boiler. An *air vent* must be provided in the return main where it drops down below the water line in the boiler. In small installations, the vent may consist simply of a ¾-inch pipe, with a check valve opening

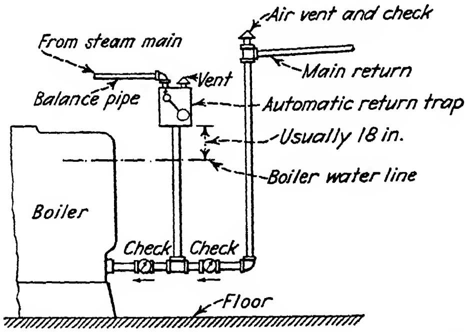


FIG. 184.—Typical connections for automatic return trap. (*From A.S.H.V.E. Guide*, 1936, *Chap.* XXXI.)

outward. A check valve is inserted in a return main near the boiler, and a vertical pipe is run up to the bottom of the return trap which is usually located so that the bottom is about 18 inches above the water line in the boiler. Some traps, however, are connected to the piping so that the bottom of the return trap is

placed as close as 8 inches above the water line in the boiler. When this is the case, a second check valve is installed in the main return pipe near the place where the pipe enters the boiler, as shown in Fig. 184.

Downfeed, Two-pipe Vapor System.—When the piping of a two-pipe vapor system is laid out so that the steam is carried to the top of a building and from there distributed downward by vertical risers, it is called a "downfeed," two-pipe vapor system. In a piping arrangement of this kind, the horizontal supply main at the top of the building has a slope downward from the top of the vertical steam-supply line, sloping to the farther ends of each branch line. The branch steam pipes are connected to the

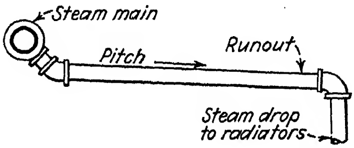


Fig. 185.—Runout designed for dripping steam main. (*From A.S.H.V.E. Guide*, 1936, *Chap.* XXXI.)

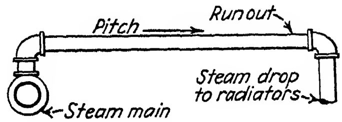


Fig. 186.—Runout designed for use where steam main is dripped at end only. (*From A.S.H.V.E. Guide*, 1936, *Chap.* XXXI.)

steam main in such a way that they make an angle of 45 degrees downward, with each of the runouts drained toward the drip connections, as shown in Fig. 185. Another system of downfeed, two-pipe vapor system is to "lead off" the branch steam pipes from the top of the steam main, as indicated in Fig. 186, and to drip the end of the steam main through the last riser, as provided for the downfeed, one-pipe system by the method shown in Fig. 185. If this latter method is adopted, however, the pipe drop at the end or ends of the mains should be increased one pipe size to provide sufficient pipe volume for this concentration of drip discharges. The steam piping of a building should be laid out with suitable reductions in pipe sizes as the various radiator connections are made until the lowest radiator runout is reached. If the building is only two or three stories high, the portion of the piping supplying steam to the lowest radiator should be increased one pipe size to permit draining water from the riser, and if the main steam-supply riser supplies more than three stories in a building, the portion of the main feeding the two

lowest radiators should be one or two pipe sizes larger, especially if these two lowest radiators are small and the normal size of the drop pipe is one inch or less in diameter. The bottom of each steam drop pipe should be provided with a *dirt pocket*, above which a *drip trap* should be installed, as shown in Fig. 187. The return feed pipes on a downfeed vapor system are the same as those used on an upfeed system, except that every steam drop pipe must have a *drip* connection at the bottom connected either into the return through a trap at the end of each line, or under a separate seal.

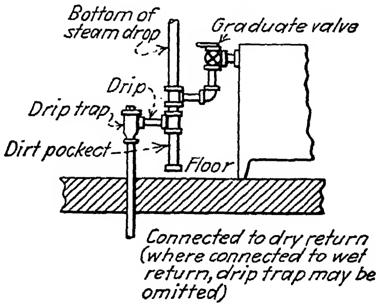


FIG. 187.—Detail of drip connections at bottom of downfeed steam drop. (*From A.S.H.V.E. Guide*, 1936, *Chap.* XXXI.)

Open or Atmospheric Heating System.—The so-called open or atmospheric heating system is always provided with gravity-return piping to the boiler, or to a

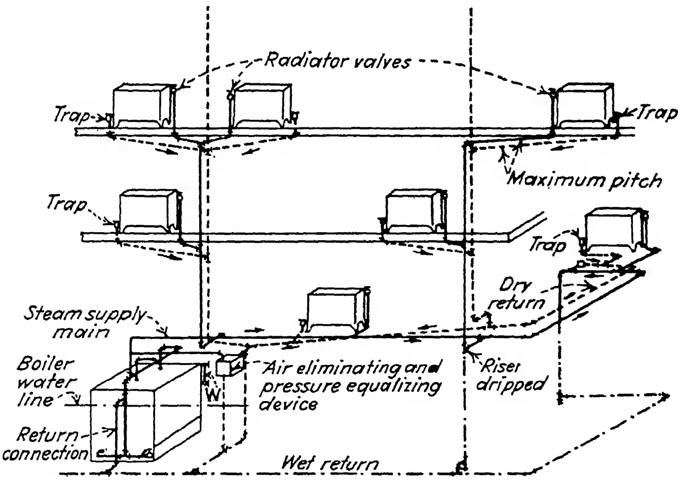


FIG. 188.—Typical atmospheric system with automatic return traps. (*From A.S.H.V.E. Guide*, 1936, *Chap.* XXXI.)

waste line. It may be provided with either the ordinary radiator valves (page 259) or with plugcock packless valves. There are no automatic air valves on the radiators, but ther-

mostatically operated traps on the radiator return pipes are used, so that the air that collects in the radiators is readily removed through these traps and expelled to the atmosphere. The return pipes are open to the atmosphere at all times, usually by the method of extending the return risers to the top of the building where they are either connected together in groups and carried through the roof, or extended through the roof individually. The condensed steam from the return drips may be returned to the boiler by so-called condensation return pumps which are vented to the atmosphere. A typical atmospheric return system with an automatic return trap is shown in Fig. 188.

Vacuum Heating System.—A so-called vacuum system of heating does not mean that a vacuum has been maintained in all the pipes of a system. As a rule, in the vacuum systems, all the steam-supply lines carry steam at low pressure. It is only in the return pipes that a vacuum is maintained. The usual accessories for a vapor system are needed for a vacuum system. These include quick-opening radiator valves, thermostatic traps, and a means for expelling the air from the return piping of the heating system by a vacuum pump. In a vacuum system, all the drip pipes must pass through thermostatic traps before they are connected to the return side of the heating system.

Arrangement of Vapor-heating Systems.—A very simple arrangement of a vapor-heating system is shown in Fig. 189. The return pipes which, in a vapor system, as already explained, contain only air and water, slope downward toward the boiler, while the steam-supply lines slope downward away from the boiler. The air is driven out of the system when the radiators and the main-supply piping are filled with steam. Air is discharged readily and effectively from the traps for the reason that it is heavier than steam, and consequently settles to the bottom of the radiator where it is in a favorable position to be discharged through an open *thermostatic trap* or similar device for evacuating air. When the steam supply from the boiler becomes reduced —usually for the reason that there is a reduction in the heat supply—the pressure in the steam-supply mains and in the radiators as well as in the boiler, falls below atmospheric pressure and with that condition existing, the boiler generates steam that is at a temperature below 212°F., just as in the case of a vacuum

system. The simple equivalent of a *vacuum* system of heating as shown in outline in Fig. 189, has the disadvantage that there may be in the system unbalanced pressure conditions, which may be readily explained by reference to Fig. 190. In ordinary operation,

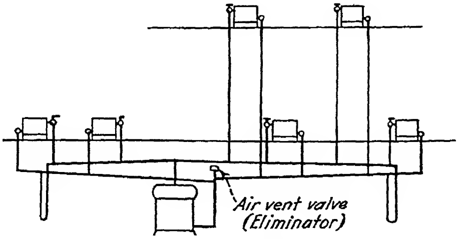


FIG. 189.—Simple vapor-heating system.

a *vapor* system has a low pressure (only ounces per square inch gage pressure) in the main steam-supply pipes, and has approximately atmospheric pressure in the return pipes. When, however, the pressure in the boiler happens to increase above the normally low pressure, an equivalent head* of water is raised in the vertical "return" pipe *R*; but the pressure head in that pipe must not exceed that equivalent to the distance *d* or the return main will be flooded with this water and the system will not operate satisfactorily, mainly because the water from the return pipes will not enter the boiler. The installation of a boiler intended for a low water line makes the occurrence of this condition less frequent.

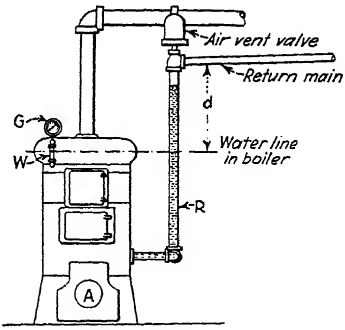


FIG. 190.—Unbalanced pressure condition in steam vapor-heating system.

In order to make sure that the vapor system will work properly in spite of occasional excessive pressure in the return system (that is, a pressure above the few ounces per square inch gage pressure and intended for normal operation) it is necessary to provide some means of forcing the water back into the boiler. In a large installation, usually larger than those intended for single residences, a

* Head of water is used commonly to measure pressure, especially draft in the firepot of an oil-burning heater.

boiler-feed pump is frequently used for this service. In small buildings, however, some other less expensive method and one requiring no special attention is required. The method most generally used for returning the condensed steam to the boiler by a positive method, when it is impractical to use a boiler-feed pump or a vacuum pump, is to use an *alternating-return* trap for handling

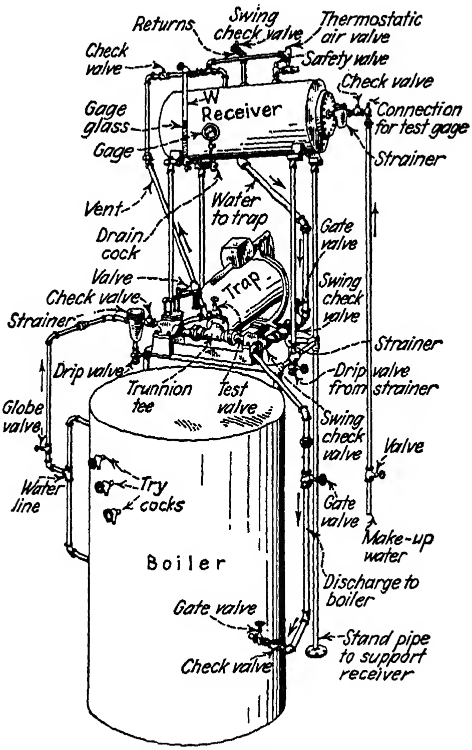


FIG. 191.—Direct-return tilting trap for returning condensed steam to boiler.

the condensed steam. This trap can be used for forcing water from the return pipes back into the boiler, as in the case when the static head d in the water column in the vertical pipe R in Fig. 190 becomes greater than the boiler pressure. The installation of the alternating-return trap in such cases insures safety and the satisfactory operation of the system under varying conditions.

Alternating-return Traps.—These devices—really alternately filled receivers called automatic return traps—consist in most instances of a small metal container with an internal float so arranged that when the condensed steam will not flow into the boiler under its own pressure, it will be discharged into this metal container until the level has risen high enough to raise the float or equivalent device which operates automatically a valve in a pipe which discharges steam into the metal container at the boiler pressure, thus equalizing the pressures in the container and the boiler, so that water from the return piping will be discharged into the boiler. Figure 191 shows a direct-return tilting trap and receiver properly connected for automatic feeding a boiler for a

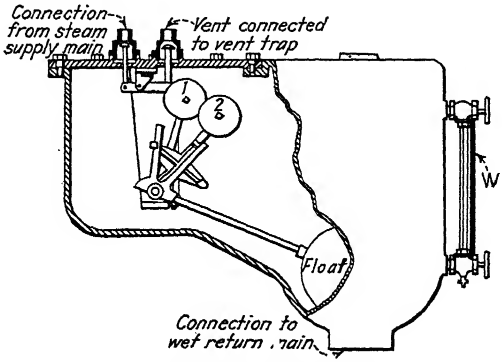


FIG. 192.—Simple alternating-return trap.

system of return pipes that deliver the condensed steam to the receiver. An illustration of a simpler alternating-return trap and its installation is shown in Figs. 192 and 193.

One of the principal advantages of a vacuum system in which the condensed steam is removed from the return system of piping by a *vacuum pump* is that it permits the location of radiators below the level of the return main, or below the water level in the boiler.

Auxiliary-fan Systems.—The method of heating and ventilating buildings by the use of a ventilating fan (page 252) to serve as a means of discharging into the various rooms fresh air or recirculated air after it has been heated, is a method that has been in general application for many years for the heating and ventilation of schools, theaters, office buildings, and factories. In the

operation of this system, the air for warming the rooms in the building is drawn or forced through a suitable heater and discharged by a fan or blower into ducts which conduct the heated air to registers placed in the rooms to be warmed. Sometimes a by-pass damper is placed in the casing of the heater so that part of the air that is to be discharged into the rooms will pass through the heater and part around it. In this way, the proportions of cold and heated air may be so adjusted as to give the desired temperature to the air entering the rooms. In buildings where several rooms are to be heated and ventilated in this way, a main or primary heater may be located at the ventilating

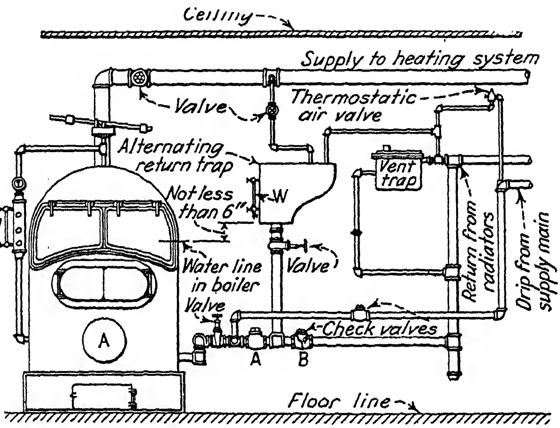


FIG. 193.—Typical installation of alternating-return trap.

fan or blower for warming the air, and then small secondary coils or heaters may be placed at the bottoms of the ducts leading to the different rooms.

One of the great advantages of the fan system is that it insures a satisfactory air circulation at all times, irrespective of wind direction; it makes possible also the addition to the heating system of both filters for cleaning the air that is circulated to the rooms and of a cooling coil in the place of a heating coil for the cooling of the rooms in hot summer weather. In many heating systems now being installed in private houses, the fan is really an important part of the equipment. The operation of an auxiliary fan greatly improves the effectiveness of a gravity system (page 291) of hot-air distribution, where, without the

fan, the quantity of air which flows to any of the registers depends on the frictional resistances to air flow. With the addition of the fan, however, the effect of the fan is so large in comparison with that producing a gravity flow of air, that most of the difficulties of a gravity system are eliminated, with the result that the ducts which have the least frictional resistance will have their flow greatly increased by the fan, and as there are usually the short first-floor ducts, the rooms which they supply will receive an increased amount of heat, while the more remote rooms which were previously underheated may receive even less heat proportionally than before. This is a real difficulty that occurs in the installation of fan or blower equipment in a building, and particularly in a single house which has been heated previously with a gravity system. The remedy, however, is easy, as it is not difficult to place dampers suitably adjusted in all the ducts supplying registers throughout the building, so that the flow of heated air will be properly adjusted for the requirements of the various rooms.

Possible Disadvantage of Forced-warm-air Distribution.—As a rule, if the fan selected is of suitable size and is properly installed, it will serve a useful purpose in a warm-air-heating system or in a single-unit indirect-heating system intended for either steam (including vapor) or hot water, for the reason that it makes possible a positive circulation of heated air into the various rooms, in always approximately the same proportion. The installation of a ventilating fan may therefore be of considerable value for improving the warm-air distribution in a poorly operating heating system. The fan cannot, however, improve conditions very much, if there is not enough chimney draft to maintain a sufficiently high rate of combustion in the furnace to supply the required amount of heated air, or if the ducts and pipes carrying the warm air are so small that air friction excessively reduces the flow.

The case also occurs where the distribution system for natural or gravity flow of the heated air is so well designed, and is so effective for average temperature conditions, that a fan will be of little value, and where the fan may actually have more effect in interfering with the proper flow of the heated air by reason of the fluid friction of the blades, than in accomplishing the improved results.

A typical case where a fan is used to obtain a positive distribution of heated air from a warm-air heater is shown in Fig. 194. In this case the fan is placed in the duct which supplies both the fresh air and the recirculated air to the air intake at the base of the furnace.

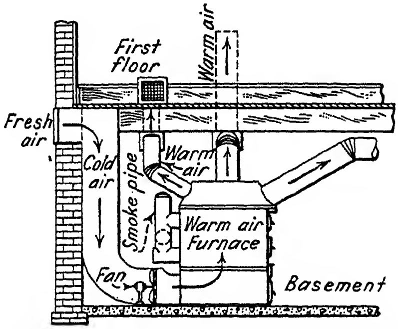


FIG. 194.—Positive warm-air distribution with centrifugal fan.

It is desirable that the distribution of fresh and recirculated air entering a hot-air furnace or the casing of a single unit of an indirect-heating system (page 250) should be adjusted by the use of baffle plates (page 102) and inlet boxes to secure a somewhat even air distribution over the heating surfaces so that there may

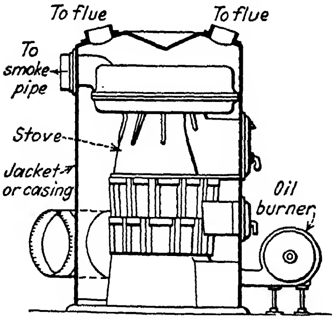


FIG. 195.—Cast-iron warm-air heater with oil burner.

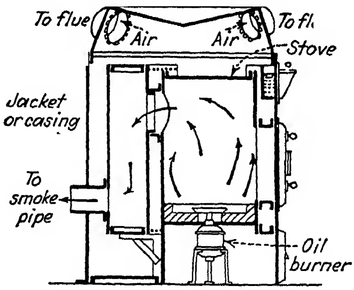


FIG. 196.—Welded steel warm-air heater with oil burner.

be practically the same temperature in all the pipes and ducts supplying registers in the rooms to be heated.

Typical warm-air heaters without fan equipment are shown in Figs. 195 and 196. The first of these is of cast-iron construction, and the other is welded-steel construction

Duct Sizes for Warm-air-heating Systems.—In a simple gravity system, the size (in square feet) of each of the basement warm-air pipes leading to a room is called the *room basic factor*, which is used in the Code of the *National Warm-air Heating and Air Conditioning Association* for determining the size of ducts for warm-air heaters. This *room basic factor* B_f is calculated from the following empirical formula:

$$B_f = \frac{G}{\text{[illegible]}} + \frac{W}{f} + \frac{C}{f} + \frac{A}{f} + V$$

where G = nominal area of glass including full window or door openings, square feet.
W = net outside wall area with full door and window openings deducted, square feet.
C = ceiling area adjacent to unheated spaces, square feet.
A = floor area adjacent to unheated spaces.
V = volume of air renewed every hour (room volume $\times$ number of air changes per hour), cubic feet.
f = factor taken from Table XX.

The formula stated is intended for 70°F. difference in temperature between the inside and outside air for approximately maximum heating requirements. If this temperature difference is *more than* 70°F., the Code of the Association requires that 1.5 per cent per additional degree difference be added to the room basic factor as calculated, or, on the other hand, that 1.5 per cent should be deducted for each degree Fahrenheit difference that the temperature difference is less than 70°F. Rooms having unusually cold exposure (mainly those facing the northeast or northwest, should have the room basic factor B_f increased by about 15 per cent in order to obtain satisfactory heating. The sum of all the room basic factors is the *house basic factor* F, which is the principal item to determine in the size of the warm-air heater (page 291) that is required.

Example.—An illustrative exercise to explain the use of equation (25) may be taken from the application of the following data for the calculation of the room basic factor (B_f): The room for which this calculation is to be made is 12 feet wide, and the ceiling height is 8 feet. There is one exposed wall in the room, and in this exposed wall there are two windows, each 3 $\times$ 5 feet. This room is directly over a heated basement or cellar, so that the term A in the formula equals 0. Similarly, the second floor rooms over the one being considered are also heated, so that the term C = 0. The exposed wall is a frame construction built up of siding, paper, sheathing, studding, lath,

TABLE XX.—VALUES OF FACTOR f FOR USE IN CALCULATING WARM-AIR-PIPE SIZES FOR GRAVITY AND MECHANICAL SYSTEMS*

		Factor f
Exposed wall:		
No. 1*a*.	Frame wall constructed of siding, paper, sheathing, studding, lath, and plaster	60
b.	Same as (1*a*) construction substituting ½-inch fibrous board or equivalent for the lath	80
c.	Same (1*a*) construction with additional 3½-inch insulating fill between studding	140
	For stucco on frame walls, use the same values as for frame with siding, as shown in (1*a*), (1*b*), and (1*c*).	
No. 2.	9-inch brick wall plastered on one side	40
No. 3*a*.	9-inch brick wall, air space, furred, and plastered	57
b.	Same as (3*a*) construction substituting ½-inch fibrous board or equivalent for the lath	84
No. 4.	13-inch brick wall, plastered on one side	52
No. 5*a*.	13-inch brick wall, air space, furred, and plastered	69
b.	Same as (5*a*) construction, substituting ½-inch fibrous board or equivalent for the lath	97
No. 6.	4-inch brick, 4- or 8-inch hollow tile plastered	57
No. 7*a*.	4-inch brick, paper, sheathing, studding, lath, and plaster (brick veneer)	58
b.	Same as (7*a*) construction substituting ½-inch fibrous board or equivalent for the lath	84
c.	Same as (7*a*) construction with additional 3½-inch insulating fill between studding	158
No. 8.	Stucco on 8-inch hollow tile, and plaster	48
No. 9*a*.	Stucco on 8-inch hollow tile, furred, and plastered	65
b.	Same as (9*a*) construction substituting ½-inch fibrous board or equivalent for the lath	95
Ceiling—with attic space above:		
No. 10*a*.	Lath and plaster without floor above	50
b.	Same as (10*a*) construction substituting ½-inch fibrous board or equivalent for the lath	70
c.	Same as (10*a*) construction with additional ½-inch fibrous board or equivalent nailed on top of joists	90
d.	Same as (10*a*) construction with additional 3½-inch insulating fill between joists	150
No. 11*a*.	Lath and plaster with tight floor above	90
b.	Same as (11*a*) construction substituting ½-inch fibrous board or equivalent for the lath	104
c.	Same as (11*a*) construction with additional 3½-inch insulating fill between joists	183

* Abstracted from the *Code* of the National Warm-air Heating and Air Conditioning Association, 1936 ed.

TABLE XX.—VALUES OF FACTOR f FOR USE IN CALCULATING WARM-AIR-PIPE SIZES FOR GRAVITY AND MECHANICAL SYSTEMS.—(*Continued*)

	Factor f
No. 12*a*. Metal without floor above	40
b. Same as (12*a*) construction with additional ½-inch fibrous board or equivalent between metal and joists	65
c. Same as (12*a*) construction with additional ½-inch fibrous board fastened on top of joists	85
d. Same as (12*a*) construction with additional 3½-inch insulating fill between joists	145
No. 13*a*. Metal with tight floor above	75
b. Same as (13*a*) construction with additional ½-inch fibrous board between metal and joists	95
c. Same as (13*a*) construction with additional 3½-inch insulating fill	176
Ceilings—without attic space above—part of the roof:	
No. 14*a*. Lath, plaster, rafter, sheathing, any type of shingles or roofing	57
b. Same as (14*a*) construction substituting ½-inch fibrous board or equivalent for the lath	74
c. Same as (14*a*) construction with additional 3½-inch insulating fill	130
Floors over exposed or unheated spaces:	
No. 15*a*. Double floor, on joists	42
b. Same as (15*a*) construction with additional ½-inch fibrous board fastened to bottom of joists	88
c. Same as (15*a*) construction with sheathing fastened to bottom of joists and with additional 3½-inch insulating fill between joists	140

The substitution of ½-inch insulating materials for sheathing should not be considered as having any additional value.

For *walls and doors* between heated and unheated spaces divide the value of f by 2.

and plaster. The value of the factor in the formula for this construction is given as No. 1*a* in Table XX, with a value of 60. Each window has a glass area of 3 by 5 feet or 15 square feet, and the glass area for two windows is 30 square feet. The total area of the exposed side including the windows is 96 square feet and, after deducting the window area of 30 square feet, is 66 square feet. The volume V of the room is $12 \times 12 \times 8$ feet or 1,152 cubic feet. From these data, then, the room basic factor B_f may be calculated,

$$B_f = \frac{G}{12} + \frac{W}{60} + \frac{V}{800}$$

$$(A = 0 \text{ and } C = 0).$$

$$B_f = \frac{30}{12} + \frac{66}{60} + \frac{1152}{800} = 5.04.$$

TABLE XXI.—DATA NUMBER USED FOR DETERMINING DIAMETERS (INCHES) FOR ROUND-PIPE SIZES*

Air velocity, in round pipe, feet per minute	Air temperature at register, °F.						
	120	125	130	135	140	145	150
200	13.7	12.6	11.6	10.7	10.0	9.4	8.9
250	11.0	10.0	9.3	8.6	8.0	7.5	7.1
300	9.2	8.4	7.7	7.2	6.7	6.3	5.9
350	7.8	7.2	6.6	6.2	5.7	5.4	5.1
400	6.8	6.3	5.8	5.4	5.0	4.7	4.4
500	5.5	5.0	4.6	4.3	4.0	3.8	3.5
600	4.6	4.2	3.9	3.6	3.3	3.1	3.0
700	3.9	3.6	3.3	3.1	2.9	2.7	2.5
800	3.4	3.1	2.9	2.7	2.5	2.4	2.2
900	3.0	2.8	2.6	2.4	2.2	2.1	2.0
1,000	2.7	2.5	2.3	2.2	2.0	1.9	1.8

* Abstracted from the *Code* of the National Warm-air Heating and Air Conditioning Association, 1936 ed.

It will be assumed in this case that the velocity of the air in the duct to be calculated is 300 feet per minute, and that the temperature of the air discharging into the room through the register is 150°F. For these conditions, the diameter in inches from Table XXI is 5.9. Table XXII is used to find the rectangular duct dimensions that are equivalent in area and air resistance to circular ducts of which the diameters are given in the columns of the table.

TABLE XXII.—CIRCULAR EQUIVALENTS OF RECTANGULAR DUCTS FOR EQUAL FRICTION

The tabulated numbers in the columns of the table are diameters

One side of rectangular duct, inches	Other side of rectangular duct, inches											
	4	5	6	7	8	9	10	11	12	13	14	15
8	6.1	6.9	7.6	8.2	8.8							
10	6.8	7.7	8.4	9.2	9.8	10.4	11.0					
12	7.4	8.3	9.2	10.0	10.7	11.4	12.0	12.6	13.2			
14	7.9	8.9	9.9	10.8	11.5	12.3	12.9	13.6	14.3	14.9	15.4	
16	8.4	9.5	10.5	11.4	12.3	13.1	13.8	14.5	15.2	15.8	16.5	17.1
18	8.9	10.0	11.1	12.1	13.0	13.8	14.6	15.4	16.1	16.8	17.4	18.1

Heating Surfaces of Small Boilers.—The heating surface of an oil-burning boiler is the surface inside the boiler which has water

on one side and the hot gases from the combustion of the oil fuel on the other side. The efficiency of a boiler is, as a general rule, much higher when the ratio of the heating surface of the boiler to the surface in its firepot is large than when it is small. In small sectional boilers it is usual to allow 20 to 30 square feet of heating surface to 1 square foot of projected firepot surface. In small *steam-heating*, oil-burning boilers it may be expected that there will be an evaporation of water amounting to about 2 to 3 pounds per hour for each square foot of heating surface.

In small oil-burning heating boilers, the greater part of the heat is transmitted to the water in the boiler by the so-called "fire surfaces"; that is, those surfaces which are in the path of heat rays that come directly from the flame of the oil burner.*

Steam-boiler Rating.—The customary rating of sectional (page 99) and other types of small boilers for house-heating is in terms of *radiation surface* (page 292) in square feet in a heating system that the boiler can satisfactorily provide for. Still another rating is the number of British Thermal units (B.t.u.) per hour (page 19) that are transferred from the flame of the oil burner to the water in the boiler.†

Selection of Size of Cast-iron Steam Boilers.—The really scientific method of determining the heating capacity of any kind

* Although the practice in regard to oil-burning steam boilers is somewhat different from the conditions in cast-iron coal-burning boilers, the usual designing principle in regard to the ratio of fire surface to flue surface is often useful for comparison. In small, cast-iron coal-burning boilers, there is about 50 per cent more fire surface than there is *flue* surface.

† The rating of cast-iron sectional boilers is quite different from that of the ordinary power-plant boiler that is frequently rated in what is called "boiler horsepower," which is the equivalent of 34.5 pounds of steam evaporated per hour "from and at" 212°F. For the evaporation of 1 pound of water into steam at these conditions, the transfer of 970.2 B.t.u. are required, making the "boiler horsepower" equivalent to 33,472 B.t.u. per hour. It is a rough and ready rule to allow 10 square feet of heating surface as the equivalent of 1 boiler horsepower in fairly efficient types of boilers, and on this basis, 1 square foot of heating surface would transfer to the water 33,472 ÷ 10, or about 3,347 B.t.u. per hour, which, for the conditions of evaporation "from and at" 212°, would mean the evaporation of 3,347 ÷ 970.2 or about 3.5 pounds of water per hour. The term "boiler horsepower" is, however, not so significant in boiler ratings as it was at one time. The B.t.u. rating, even for power units, is more satisfactory than that of boiler horsepower.

of boiler is to compute the heat transfer in terms of British thermal units per hour from the flame of the oil burner to the water in the boiler, and then to re-evaluate this heat capacity (in heat units) in terms of radiation surface that the boiler can satisfactorily heat.

For the calculation of the heating capacity required of a boiler, the following items must be determined:

1. Heat to be distributed to all radiation surfaces connected to the heating system. This amount of heat should be calculated on the basis of the difference in temperature between the walls of the several rooms in the building; or in the case of the outside walls of rooms, on the basis of the difference in temperature between the minimum outdoor temperature and the inside room temperature.* Calculation methods are explained on page 302.
2. Heat lost from both covered and uncovered parts of the boiler and the distributing steam piping.
3. Heat required for a hot-water heater for domestic or similar service and, other special heating equipment that may be attached to the boiler.

Starting Load of Boiler.—The capacity of the boiler, as calculated from the sum of the above three items, is the number of heat units to be provided by the boiler during minimum-temperature weather, and after the rooms in the building have been heated to the average winter room temperature. It is a common practice to permit the temperature in the rooms of a building to be very much reduced below what it is for the ordinary working or office time, during those hours when practically no one is using the rooms, especially at night, Sundays, and holidays, so that the maximum-capacity rating of a boiler ought to be somewhat larger than the size that would be calculated from the three above-mentioned items. For this reason, a so-called "starting load" of a boiler should be taken into account, which includes:

1. Additional heat that must be supplied to the radiator surface and piping of the heating system during the time that the room temperatures are lower than they will be when the normal temperature is obtained.
2. Heat required to raise the metal in the radiators and piping to the normal or room temperature.

It is difficult to calculate in B.t.u. the allowance that should be made for starting load, as the amount will depend somewhat on the normal heating requirement of the heating system. The

* For the latitude of Philadelphia, New York, and Boston, a satisfactory minimum temperature is 0°F.

difficulty in direct calculation has been overcome by making a percentage allowance for the starting load. The American Society of Heating and Ventilating Engineers recommends that *for oil- and gas-burning boilers this allowance should be* 25 *per cent.**

Shutting Down Oil Burner at Night.—In a house where the bedroom windows are opened very little in severely cold weather, or where the doors of open-air bedroom windows are tightly closed at night, experiments on oil- and gas-burning heaters and boilers show that the consumption of fuel is practically the same throughout a 24-hour day, if the temperature of the air in the living room of the house is not reduced during the night more than 10°F. In other words, if the room thermostat is set at 70°F. during the day and is set at 68°F., 65°F., or 60°F. at night, the fuel used by the oil burner will be practically the same during every 24-hour period. The reason for this is that within these limits, there will be about as much fuel burned in the early hours of the morning in order to make a house comfortably warm to equal the fuel that would be saved during the night by temperature reduction.†

The engineers of the General Electric Company in Boston and of the Boston Consolidated Gas Company state that within an 8 to 10°F. temperature reduction at night, the total 24-hour fuel consumption is approximately the same.

The important exceptions to these data would be cases where bedrooms are cooled excessively at night with doors partly open, and in rooms where children are sleeping with wide or partly wide open windows. Still another exception is the case where there are loose and poorly fitting doors and windows, so that the whole house will get very cold at night.

The same considerations, however, do not apply to coal or coke burning in house heaters, for the reason that it is a practical necessity to reduce the house temperature at night on account of the limited amount of fuel that can be put into the firepot to carry the heating load during the night. The firepots of most heaters and boilers are not large enough to carry the heating load

* American Society of Heating and Ventilating Engineers "Guide," 1936, page 440.

† In the New York-Philadelphia District, it is generally assumed that the temperature reduction for equal oil burning costs may be as much as 15°F.

of a house at the normal daytime temperature throughout the night.*

Ducts or Pipes for Warm-air Distribution to Rooms.—In the case where round pipes are used to distribute the warm air from a warm-air furnace, the cross-sectional areas of the individual pipes going to each room are obtained by multiplying the room basic factor B_f as calculated with equation (25) by the data number obtained from Table XXI corresponding to the allowable temperature and air velocity in feet per minute in the duct. When the warm air is to be distributed in *rectangular* ducts instead of round pipes, the equivalent dimensions of the rectangular ducts are obtained from Table XXIII.

Registers for the discharge of warm air, when located below the "breathing level" of the occupants of a room, may have an air-discharge velocity of about 300 feet per minute, but when the registers are located high up on a wall so as to be a considerable distance above a breathing level, an air velocity of 500 feet per minute is allowable.

Return-air Ducts for a Gravity-distribution System.—The sizes of ducts needed for returning air to a warm-air heater or to the casing of an indirect steam or hot-water heating system so that this air may be recirculated should be at least equal to the areas of the supply ducts.

Calculation of Size of Fan and Grate Area of a Warm-air Heater for a House.—The capacity of ventilating fans is usually stated in a rating of cubic feet per minute of air delivery. A ventilating fan should therefore be selected that will have sufficient capacity to handle the air volume required for all the rooms in the house with an additional capacity of 15 per cent.

The proper size of the fan to be used in a given case will be determined, however, not only by its delivery capacity in cubic feet per minute, but also by the static head in inches of water pressure (page 349) against which the fan will have to operate. This static head is really the static pressure required to overcome the friction of the pipes and ducts through which the heated air is to be moved in order to be discharged from the several registers in the house. In large installations, the static pressure can be calculated quite accurately, but in the small fan units that are

* *Univ. Ill., Eng. Exp. Sta. Bull.*, p. 80.

required for residences, it is customary to estimate the static head from the data available.

In cases where the air is washed or filtered, the resistance (in inches of water) of the air washer, or the filtering device must be determined and added to the static head due to the resistance of the pipes or ducts, in order to get the total static head against which the fan will be required to operate.

Grate Area of Coal-burning Warm-air Heater.—The size of the warm-air heater for burning coal may be determined according to usual practice by its grate area, and this important factor in warm-air-heater selection is calculated according to the Code already referred to (page 277) by equation (26) in which a is the grate area in square feet; F is the house basic factor (page 277); E is the efficiency of the furnace (measured at the bonnet and usually assumed to be about 65 per cent); H is heating value of the fuel per pound (usually 12,000 B.t.u. per lb. for good anthracite coal); and R is the rate of combustion in pounds of coal per square foot of grate per hour (usually assumed to be 6). A factor entering the formula is the ratio of the amount of heat delivered at the registers to the heat leaving the bonnet of the warm-air heater. This ratio is usually about 0.85. In terms of the symbols just explained, the grate area in square feet is

$$a = \frac{1{,}000 \times F}{0.85 \times E \times H \times R} \tag{26}$$

or if the average values just stated for these symbols are inserted in the formula, the formula becomes

$$a = \frac{1{,}000 \times F}{0.85 \times 0.65 \times 12{,}000 \times 6.0}$$

or in square inches $= 3.6 \times F$ (approximately).

Oil-fired Warm-air Heaters.—Combustion conditions in a warm-air furnace intended for the combustion of solid fuel are not exactly comparable when some other kind of fuel as, for example, oil or gas, is burned. A warm-air heater intended for burning coal or coke has a firepot that is designed to contain a thick bed of solid fuel; and the surfaces for heating the air to be circulated through warm-air ducts and registers in the building are intended to receive mainly radiant heat (page 245) from the top surface of this thick bed of coal or coke. The air to be

circulated through the ducts and registers absorbs heat by passing over the air-heating surfaces of the warm-air heater which are, of course, on the opposite side, and not on the side receiving radiant heat from the fuel bed. A well-designed warm-air heater makes provision also for the passage of the air around the outside surfaces of the firepot, so that considerable heat is absorbed also from that source.

When oil is used for fuel and is delivered into the firepot by a suitable atomizing device, there is considerable actual absorption of radiant heat by the heating surfaces, and most of the heat transfer is (1) from the flame of the burning oil and (2) from the hot gases produced by combustion as they impinge on the surfaces inside the heater with which the burning or burned gases come into contact. In this kind of combustion the hot gases from the oil flame raise to a high temperature the heating surfaces in the warm-air heater, these surfaces having hot gases on one side and the air to be heated on the other. Therefore it should be obvious from this discussion that the distribution of heating surfaces for ideal conditions should be different in a warm-air heater intended for the combustion of oil (or gas) than it is for a heater of this kind intended for burning solid fuel; the principal difference is that for oil burning there should be a larger amount of heating surface to be heated by the hot gases after they have left the firepot. In other words, an oil-fired warm-air heater should have a much larger amount of indirect-heating surface than is necessary for a furnace burning solid fuel. For this reason, it is desirable, at least in new heating installations, to install a differently designed warm-air heater for oil heating than would be installed for heating with solid fuel. In fact, a satisfactory design for oil burning should be like the layout shown in Fig. 197. It will be noted that this equipment includes a ventilating fan driven by an electric motor. The fan is intended for the positive distribution of the heated air to the various warm-air ducts and registers in the building. In this design, the transfer of heat from the burning or burned oil fuel to the air to be heated takes place in the heating chamber *H*, which consists of narrow passages that are made by inserting a number of vertical baffle plates to obstruct the free flow of air and therefore reduce its velocity through the passages. In this figure, the oil burner is *B* and the water-spray humidifier is *W*.

For cleaning the air before it is distributed, an air filter *I* is provided. The fan *F* is included in the equipment for obtaining positive circulation of the warm air through the building. The fan is operated by the electric motor *M*. It is more difficult to operate successfully with oil a warm-air heater that has been designed for solid fuel than it is to operate it with solid fuel or gas, for the reason that when burning solid fuel or gas fuel there is a slight negative pressure in the firepot due to the draft

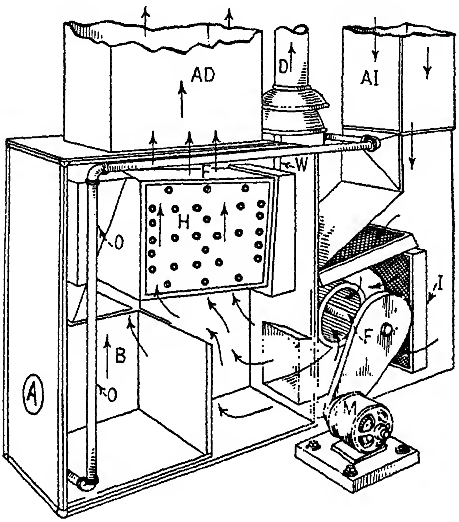


Fig. 197.—Heater with air-conditioning attachment.

up the chimney. When oil is burned, on the other hand, especially in the so-called gun-type of burner, there is occasionally a slight pressure in the firepot and in the combustion chamber, so that if there are air leaks in the casing of the furnace, the gases that result from the combustion of the oil may get into the air-heating chambers where, because of the odor of oil, they will be very objectionable. Some types of oil burners are noisy in operation, and it is not unusual for the noise from such burners to be transmitted through the hot-air pipes and ducts to the rooms in the building. In the installation of an oil burner, very great care should be taken to avoid the transmission to any part of a warm-air heater or a boiler of any vibration noise in a fan or motor, as in that case the noise will be likely to be carried

along with the warm air to the registers in the rooms that are heated.

Auxiliary Equipment Needed for Air Conditioning in Connection with Warm-air Heaters.—Air conditioning for residences and other small buildings is usually understood to be somewhat different in its objectives from air conditioning for large buildings, as, for example, theaters, office buildings, department stores, or

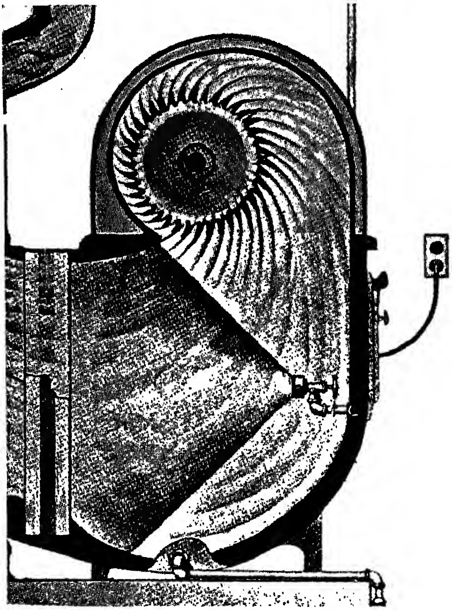


FIG. 198.—Air discharge from centrifugal fan into water spray for air-conditioning unit.

factories. The equipment usually installed for the air conditioning of residences is intended mainly for the distribution of humidified warm air during the heating season with such positive distribution as can be obtained with the inclusion in the equipment of a ventilating fan. In order to distribute only clean air to the various rooms, an *air filter* (page 287) is often a part of the so-called air-conditioning equipment for the humidification of the air. A water spray is usually provided which, if given a sufficient supply of water, can be effective for humidifying the warm air distributed to the various rooms in winter. Both the

air filter and the water spray can therefore be used to good advantage in such a system for the improvement of the condition of the air and the comfort of the occupants of rooms. The principal advantage of air conditioning, however, as usually understood, is that it increases the comfort of rooms, especially during very warm weather.

However, the kind of air conditioning that is possible with the equipment just described makes very little provision for comfort during hot days and nights in the summer season. By the operation of the ventilating fan, of course, there will be air distribution coming from the basement or cellar into the

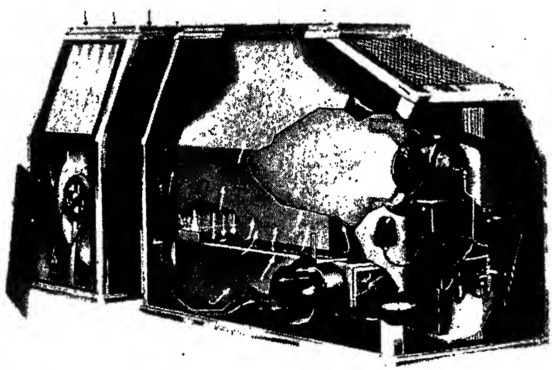


FIG. 199.—Oil-fired heater with centrifugal fan in separate unit.

rooms, but the cooling effect will be very limited; in fact, as a rule, the humidity of air during a hot season is likely to be too great, so that in most of such cases, the water spray, if operated, would tend to increase rather than decrease the discomforts of warm weather. The air cleaner, of course, would be as effective in summer as in winter for clearing the air, and would insure, if properly taken care of, the distribution to all of the rooms of fairly well-cleaned air.

A modification of the system that has some merit is the inclusion in a warm-air-heater installation of a finned coil of thin metal, similar to those used in the so-called "unit" systems of heating and cooling (page 251) with the object of circulating through the passages of this coil cool water from the city water mains or some other water supply. The effectiveness of this

variation of the general system will depend, of course, on the temperature difference between the circulated water and the temperature of the air that is being circulated by the ventilating fan. Figure 198 is a humidifying device and Fig. 199 is a pictorial representation of an oil-fired heater that is equipped for air conditioning.

Thermostatic Control of Combustion and of Fan for Warm-air Heater with Positive Air Distribution.—When a warm-air heater or similar heating equipment includes a ventilating fan, with intermittent combustion, as is usually the case with oil-fired burners, there are objections to the continuous operation

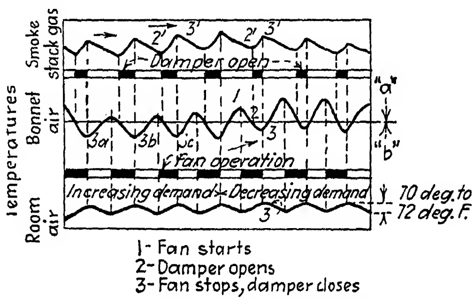


FIG. 200.—Cycle of operation of automatically controlled forced-air heating system.

of the fan. One of the objections is that when the oil burner is not operating, cold-air drafts will be felt by the occupants of rooms because of the distribution of relatively cold air from the registers. In order to overcome this difficulty, a combination of thermostats may be used to good advantage. By this arrangement, a single thermostat is placed in the air-discharge pipe of the warm-air heater for operating, by means of a relay, the electric switch for starting and stopping the motor that operates the fan and a thermostat is placed in a room for the purpose of controlling the operation of the oil burner. When the thermostat in the room starts the oil burner because of a too low temperature, the temperature of the hot air in the bonnet of the warm-air heater will immediately be raised. This temperature rise in the bonnet of the heater causes the thermostat located there to operate the fan.* This method of positive air circulation for heating is

* In this case temperature *rise* causes the closing of a circuit by a thermostat.

explained in considerable detail in "Automatic Controls for Forced-air Heating Systems" by Konzo and Hubbard (*Jour. A.S.H. and V.E.*, 1933). The chart in Fig. 200 shows very interestingly the somewhat similar cycles of operation of a system of this kind when applied to a coal-fired heater or boiler, with intermittent operation of dampers.

Warm-air Heaters.—There are two principal types of warm-air heaters or "furnaces," classified according to type of construction. One of these is the cast-iron type of which there is an illustration with an oil-burner equipment in Fig. 195. The other is the welded-steel type shown also with oil-burner equipment in Fig. 196. Considered in its simplest application, a warm-air heater is a stove enclosed in a suitable metal casing. The inside or "stove part" of a cast-iron warm-air heater may be constructed of cast-iron sections, the number of sections being increased according to the heating requirements; or it may be made of sheet steel with welded connections. In the space between the "stove part" and the thin-sheet-metal outside casing, spaces are constructed in which the air to be heated can circulate while it is "absorbing" heat. The heated air is then distributed to the rooms through a system of ducts (page 284) or *leaders*. The duct which brings into these spaces the cool air for such circulation is called the *cold-air inlet*, or *return duct*, depending on the source of the air supply that is to be heated, that is, whether it comes from out of doors or is air that has been returned to the room in which the warm-air heater is located, and is to be recirculated after being reheated. The ducts used to distribute the air after it has been heated are called "warm leaders. To distinguish the ducts according to location, the vertical ducts in the walls and partitions are called "stacks" or flues, and the connecting duct between a leader and a stack is called a "boot." An ideal air-supply system is one in which the air to be heated comes partly from the "inside" for recirculation, and partly from the outside air.

There are two warm-air-circulating systems in use. One is known as the "gravity system" and the other as the "fan-circulating system."

A reliable engineering organization has prepared the figures given in Table XXIII to show the relative costs of the three kinds of heating systems that have been discussed. It will be noted

that the indirect systems are not included in the table. This is for the reason that there is likely to be a very large variation in cost between a simple indirect-steam or hot-water system and a more complicated and efficient system of the indirect type.

TABLE XXIII.—RELATIVE COST OF HEATING EQUIPMENT AND INSTALLATION

	Hot air	Direct steam	Direct hot water
Relative cost of equipment (including boiler or heater)	9	13	15
Relative cost, including boiler or heater, after adding repairs and fuel for 5 years	29	29	27
Relative cost, including boiler or heater, after adding repairs and fuel for 15 years	80	60	50

Equivalent Radiator Surface.—The heat emission from the various types of radiators is usually based on a unit called the "equivalent square foot of steam radiator surface." This unit is defined as the amount of surface which, with a steam temperature of 215°F. in the radiator and a surrounding air temperature of 70°F., will emit heat at the rate of 240 B.t.u. per hour. It may be noticed that by the use of a unit of this kind for rating radiators, it is unnecessary to know the actual amount of surface in the radiator for the reason that the efficiency of radiator surface for heat emission varies a great deal, depending especially on the number and location of the columns in the column type or tubes in the tube type (page 255) of radiator. The simpler arrangements of columns or tubes give the higher efficiencies per square foot of radiator surface.

The heat emission of radiators of all kinds may therefore be expressed in terms of equivalent direct-steam-radiator surface by dividing the total heat emission of the radiator when tested at standard conditions of steam temperature and surrounding air temperature as already explained, and dividing this quantity of heat by the heat-emission quantity 240. In a *hot-water system*, an equivalent square foot of radiator surface is sometimes considered as emitting 160 B.t.u. per hour.* Most engineers,

* The equivalent square foot of hot-water-radiator surface is defined more completely as the amount of surface, with a hot-water temperature of about

however, discourage this unit for the rating of hot-water radiators, preferring to rate the hot-water radiators for their heat emission as when heated by steam.

Equivalent Radiation Surface of Radiators and Heaters.—The heat requirement for a direct-radiation system (page 261) of heating *is its equivalent radiation.* On the other hand, for direct-indirect radiators (page 252) in a heating system, 25 per cent must be added to the actual square feet of this kind of radiation to obtain the square feet of equivalent radiation to be supplied by a steam boiler.

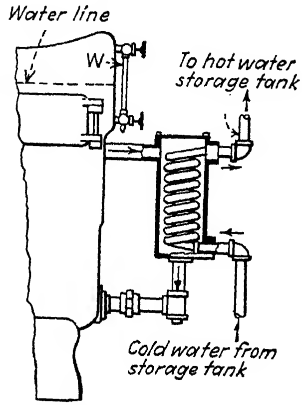


FIG. 201.—Heater for domestic hot water on oil-burning boiler.

The capacity in gallons is multiplied by 2.5* to obtain the equivalent square feet of pipe or other radiation required by a hot-water storage or service boiler.†

Heat Losses from Insulated and Bare Steam and Hot-water Pipes.—The amount of heat capacity that must be added to the requirement of a steam or hot-water boiler (or coil) to allow for the normal heat loss is generally calculated by more or less rule-of-thumb methods. For example, if the heat-insulating covering on steam or hot water pipes is 5/8 inch thick or less, the heat loss is calculated the same as it would be for bare pipes of the outside diameter of the insulation (*not* of the

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180°F. in a radiator and a surrounding air temperature of 70°F., which will emit heat at the rate of 160 B.t.u. per hour.

* This figure is based on the assumption that in severely cold weather one tankful per hour will be needed. This is probably the maximum requirement. Some designers use here 2.0 instead of 2.5.

† When the water in the storage tank does not actually circulate through the coil in the combustion chamber of the boiler but is heated indirectly by the method of circulating it through the tank so that the water from the heating coil in the boiler heats only indirectly the "service water" in the coil with connections as shown in Fig. 201, the equivalent radiation surface is found by adding to that of the house heating system one-half square foot of equivalent radiation for each gallon of the total capacity of the tank (including in this item both the net water capacity of the tank and the capacity of the coil; or, in other words, the number of gallons corresponding to the total volume of the *cylinder*). A complete installation is shown in Fig. 202.

bare pipe itself). The heat loss from bare pipes of a *steam-heating* system is usually taken as 2.0 B.t.u. per hour per square foot of outside pipe surface (thin insulation being calculated as before) per degree Fahrenheit difference between the steam in the pipe (or water in the boiler) and the surrounding air.

For a hot-water heating system, the heat loss from bare pipes is, on the other hand, 1.8 B.t.u. per hour per square foot of outside pipe surface per degree Fahrenheit difference between the water and the surrounding air.

When the pipe covering is ¾ inch thick or thicker, the heat loss from the piping is usually taken as only about 30 per cent of the figures given here for a steam-heating system, or for a hot-water heating system. It should be noted here that the *equivalent radiation* (page 292) of bare pipes carrying steam is the same as that of direct radiation, and therefore the number of square feet of *bare* piping is the same as the *equivalent* radiation of that number of square feet of pipe. Consequently the equivalent radiation of well-insulated pipes is only about 30 per cent of the number of square feet of the bare pipe when the insulation on the pipes is ¾ inch thick or thicker.

Example of Calculation of Normal and Maximum Capacity of Oil-burning Heating Systems.—A steam-heating system supplied by a boiler equipped with an oil burner includes 15,000 square feet of "equivalent" radiator surface, 2,400 square feet of pipe surface with heat insulation 1 inch thick, and 200 square feet of pipe surface *without* heat insulation. Also included in the heating requirement of the boiler is a water-heating coil (page 293) which heats the water in a 50-gallon tank. The *normal* heat requirement of this system, and also its *maximum* heat requirement are to be calculated from these data.

Item 1: Equivalent radiation of steam-heating system = 15,000 square feet.

Item 2: Equivalent radiation of insulated pipe surface (1 inch thick) equals 2,400 × 0.3* = 720 square feet.

* As already stated if the heat-insulating covering of steam pipes is ⅝ inch thick, or less, the heat loss is assumed to be the same as it would be for bare pipes; and that when the covering is ¾ inch thick, or more, the heat loss is assumed to be 30 per cent of what it would be for bare pipes. So that in one case the multiplier is unity and in the other case it is 0.3.

Item 3: Equivalent radiation of bare pipe surface equals $200 \times 1 = 200$ square feet.

Item 4: Equivalent radiation of 50-gallon tank connected to water-heating coil in steam boiler (page 293) equals $50 \times 2.5 = 125$ square feet.

Total normal heat requirement of this system equals Item 1 plus Item 2 plus Item 3 plus Item 4 = 16,045 square feet.
Normal requirement of heating system in B.t.u. per hour is

$$16{,}045 \times 0.417 = 6{,}690 \text{ B.t.u.}$$

Maximum requirement of heating system in *square feet of radiaion* is

$$16{,}045 \times 1.25 \text{ (page 283)} = 20{,}056 \text{ square feet.}$$

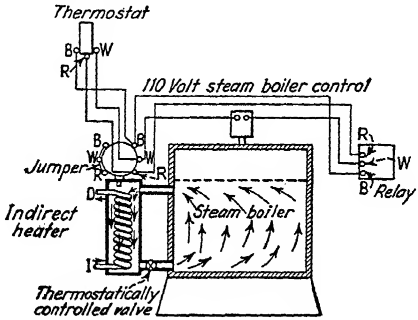


FIG. 202.—Thermostatically operated hot-water heater on steam boiler.

Maximum requirement of heating system in B.t.u. per hour is

$$25{,}672 \times 0.417 = 10{,}705 \text{ B.t.u.}$$

Hot-water Boilers with Oil Burners.—There is very little difference in the general design of boilers intended for steam and hot-water-heating systems.

Air Distribution and Duct Friction.—Air distribution is of great importance for the satisfactory heating of the various rooms in a building. Because of the possibility of producing objectionable drafts and the accumulation of layers of dead air, a number of factors must be considered in the design of a warm-air distributing system. The important factors are ceiling height, location of both outlets and return openings, and the temperature difference between the entering and the leaving air as well as also the exposure of the rooms to outside-air velocity.

In general, the procedure is to locate the warm-air outlets and the return-air intakes (if any) to distribute evenly the warm air to the various parts of a room or a building. This determines the location of the main distribution headers, and it then becomes the problem to convey efficiently the warm air to the outlets.

There is friction from the flow of air through ducts, elbows, outlets, and headers, so that it is necessary to keep these frictional losses low.

Duct Proportioning.—Three methods are in use for calculating the sizes of distribution ducts. These may be listed as follows:

1. The initial velocity may be determined first. This will determine the size of the duct, after which the velocities at other points may be calculated roughly, to arrive at the duct sizes. Obviously, this is not a satisfactory method unless a great deal of judgment is used in making the layout.
2. The maximum allowable resistance may be assumed and the ducts sized so as not to exceed this total. This method works out quite well and is very economical.
3. The ducts may be proportioned on a basis of equal friction per foot of length. This is the most satisfactory method of all. The length of the longest run is determined together with the number of elbows, outlets, and other sources of air resistance. The total friction loss of the system will be the same as if all the air were being carried the longest distance through the largest duct.

Duct sizes are calculated by this method from the relationship that the ratio of the diameter d_2 to convey Q_2 cubic feet of air per minute to the diameter d_1 to convey Q_1 cubic feet of air per minute varies approximately as the 0.4 power of the ratio of Q_2 to Q_1. Stated algebraically,

$$\frac{d_2}{d_1} = \left(\frac{Q_2}{Q_1}\right)^{0.4} \quad \text{or} \quad d_2 = d_1\left(\frac{Q_2}{Q_1}\right)^{0.4} \tag{27}$$

Also the ratio of these diameters varies as the *square* of the ratio of V_2 (the velocity for Q_2) to V_1 (the velocity for Q_1). As used here the diameter refers to the equivalent diameter of *round* pipe to carry the same capacity as a rectangular duct and has the same friction per foot of length.

The formula for equal friction per foot of length is rather difficult to use. Curves have been plotted to make computations less laborious. With the help of curves, it is a simple matter to calculate the sizes of branch ducts to handle any percentage of the total volume of air.

As an example to illustrate the use of the formula, assume that a 24-inch main duct is to be used. Leading from this main duct is a branch which is to carry 40 per cent of the total air.

$$24 \times (0.4)^{0.4} = 16.65 \text{ inches}$$

A 16½-inch duct would be used.

Similarly, if another branch is to carry 20 per cent of the total air,

$$24 \times (0.2)^{0.4} = 12.6 \text{ inches}$$

A 12½-inch duct would be used.

This computation is carried out for all the branches. Where there is return-air piping, the duct sizes are calculated similarly.

Elbows.—A change in direction of air flow is always accompanied by a frictional loss. In general, of course, the greater the radius of bend the less will be the loss. A centerline radius of 1½ diameters for round pipe and 1¼ widths for rectangular pipe is good practice. Increasing this radius means too little reduction in power consumption to be worth while. Using proper radii for the elbows, the loss in pressure for *one elbow* may be assumed about *equal to the loss in* 10 *diameters of straight pipe or duct.*

Duct Work and Dampers.—In general, ducts of galvanized sheet iron with rectangular cross section are preferred. Velocities through air ducts should be approximately as given in Table XXIV. Air velocities and temperatures through registers recommended by the American Society of Heating and Ventilating Engineers are given in Table XXV.

TABLE XXIV.—AIR VELOCITIES IN SUPPLY SYSTEMS

	Feet per Minute
Intake louver (free area normal to blades)	1,000
Aerofin heaters (face area)	500 to 600
Vento heaters (free area)	1,000 to 1,200
Fan outlets	1,000 to 2,000
Main supply duct	900 to 1,200
Branch ducts	600 to 1,000
Vertical flues	400 to 800
Inlet registers or grilles (face area)	200 to 500
Outlet registers or grilles (face area)	400 to 600

Louvers, Grilles, and Registers.—The free area through louvers (Fig. 203), grilles (Fig. 204), and registers (Fig. 205) is the actual area between the blades of louvers and registers and

through the openings of grilles, and the efficiency is the ratio of free area to total face area. The efficiency of intake louvers may

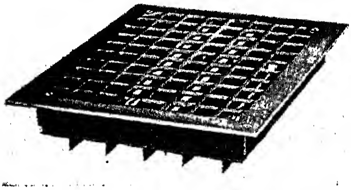


FIG. 203.—Register with multiple valves (louvers).

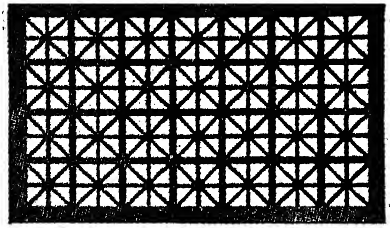


FIG. 204.—Ventilating grille.

be from 40 to 70 per cent, depending on the size and type of construction. When determining the size of the masonry opening, it is necessary to know the efficiency; and manufacturer's specifications for the louvers should state the efficiency expected. Where it is desired to provide an easy means of shutting off the air supply to a room, registers may be provided; but where accurate control of the air supply is necessary, dampers which can be locked in position are better, as they can be placed in the control of one man who is responsible for their correct operation. The design of grilles should be such that the velocities through the free area will not cause whistling or other noises (page 287) or impose excessive friction on the system. Readings taken with an *anemometer* give the velocity through the *face* area and not through the free area.

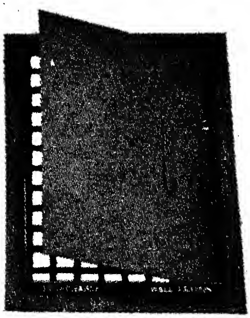


FIG. 205.—Wall-gister with sing (rear view) with single-shutter valve.

TABLE XXV.—AIR VELOCITIES AND REGISTER TEMPERATURES*

Type of building	Velocities, feet per minute							Register temperature, °F.
	Free area of heaters	Horizontal supply ducts	Supply risers	Into room	Vent outlets	Vent risers	Horizontal vent ducts and recirculating ducts	
Schools	800 to 1,000	800 to 1,000	500 to 600	300 to 400	300 to 400	500 to 600	600 to 800	90 to 120
Churches	800 to 1,000	700 to 900	400 to 600	300 to 500	300 to 500	400 to 600	500 to 700	80 to 120
Auditoriums and convention halls	800 to 1,000	800 to 1,000	500 to 600	300 to 500	300 to 500	500 to 600	600 to 800	80 to 120
Garages and industrial buildings.	1,000 to 1,400	1,000 to 1,400	600 to 1,000	400 to 1,000	400 to 600	600 to 1,000	800 to 1,200	80 to 140

* "Guide," American Society of Heating and Ventilating Engineers, p. 444, 1932.

Heating Domestic Water.—It is usual to assume a total of 15 gallons of hot water per day for each person living in a residence. Allowing 750 B.t.u. per gallon, the total heat per day per person would be 11,250 B.t.u. With oil of 141,000 B.t.u. per gallon (page 22), burned at 60 per cent efficiency, the oil required for a 30-day month would be:

$$\frac{11{,}250 \times 30}{141{,}000 \times 0.60} = 4 \text{ gallons per person } \textit{per month.}$$

If the oil burner heats domestic water only during the heating season, the above figures should be multiplied by 8 to find the *yearly* consumption. Although the heating season is often considered as lasting nine months (September 1 to May 31), the burner will be "off" much of the time at the beginning and the end of the season. During these "off" times no domestic water will be heated and some auxiliary heating apparatus must be used.

If the oil burner has year-round, or "summer-winter" control (page 156), the monthly figures must be multiplied by 12. It is true that the cold-water temperature is higher in summer, and therefore less heat is required per gallon. However, when running only to heat the domestic water, the oil burner will operate at reduced efficiency.

Domestic Water Heaters.—A steam or hot-water boiler, especially of the type having a circular horizontal cross section, is suitable for the addition in the combustion chamber of a coil for heating water. The coil may be connected directly into the hot-water system of the building, or it may be connected into a supply tank where a constant temperature will be maintained by thermostatic means. This arrangement offers, of course, a very simple method of obtaining a continuous supply of hot water, but it has the objection that it introduces an obstructing element in the combustion chamber. There is the further disadvantage that, because of the on-and-off operation of an automatically operated oil burner, there will be times when there may be no heat in the firepot of the burner; and, consequently, no hot water will be available.

CHAPTER IX

CALCULATION OF HEATING REQUIREMENTS

Heat Loss from Buildings.—An oil burner is only one part, but the outstanding part, of any heating system in which it is included. Even a well-designed and properly installed oil burner cannot give satisfaction, however, unless the other parts of the heating system are of the proper size and are efficiently arranged.

Conversion jobs in which the oil burner is the new part of the equipment, while the rest of the system has been in operation for years, are especially likely to face this difficulty. Even if the old system never gave satisfaction, the installation of an oil burner is expected to cure all its faults. In many cases, the oil-burner salesman is largely responsible for such dissatisfaction.

No oil burner is perfect, or ever will be. However, if the oil-burner salesman knows something of the principles of heating, he can place the blame for trouble where it belongs. If he can foresee and point out such troubles before the burner is installed, unpleasant reactions can be avoided. At any rate, he should know enough about the principles and types of heating systems so that he can suggest effective remedies for poor operation.

The oil burner must obviously have sufficient capacity to heat all parts, but it is equally important that the various units of the heating equipment are properly proportioned so that each room will receive its share of the heat, according to exposure requirements (page 313).

Transmission and Infiltration Heat Losses.—Heat like water "flows" from a higher to a lower level, so that when the air temperature inside a building is higher than that outside, heat will "flow" or be lost, to the outside air. This heat loss is made up of two parts: (1) Heat that flows, by conduction (page 246) through the walls, roof, ceiling, etc., that are exposed to the lower temperatures on the outside. This is the *transmission loss.* (2) In every building, cold air continually leaks in from outside

and must be heated. This is the *infiltration loss.* The important factor affecting both of these heat losses is the difference in temperature between the inside and the outside air. For the calculation of these heat losses, it is the common practice to assume a normal "room" temperature of 70°F. in residences and offices, where the occupants are seated or are only slightly active by movement.

For design purposes the outside air temperature is usually taken as about 15°F. above the minimum shown by U. S. Weather Bureau records. In the vicinity of New York City, the lowest record is −14°F., and a design base of 0°F. is commonly used. Subzero temperatures are rare and usually last only a few hours so that the heat stored in the building structure can be depended on to carry over the peak load.

Method of Heat-loss Calculation.—Present practice for heat-loss calculation is based on the fact that heat flows through walls, glass, etc., in accordance with known physical laws. Infiltration loss is treated as a separate item. By this method, the heat loss per hour H in B.t.u. is given by the following equation:

$$H = AU(t_1 - t_0) \tag{28}$$

where A = area of the walls (including glass), square feet.
t_1 = temperature of air in the room, degrees Fahrenheit.
t_0 = temperature of air on cold side of wall, degrees Fahrenheit.
U = coefficient of transmission in B.t.u. per hour per square foot per degree Fahrenheit difference in temperature.

In applying this equation, the value of the coefficient U will depend on the material, the type of construction, and the position of the wall. In this sense the word "wall" must be understood as applying to ceilings, floors, roofs, etc., as well as to its usual meaning. A great deal of research has been done to determine working values of U for various types of building construction. The "Guide" published by the American Society of Heating and Ventilation Engineers gives such values for almost all types used in modern building. (See 1936 edition, pages 112 to 125.) Table XXVI gives the data that are likely to be required in oil-burner work.

The temperature drop ($t_1 - t_0$) through walls between heated and unheated spaces, such as attics, entries, etc., is usually assumed to be one-half that through a wall between a heated room and the outside. Walls between heated rooms are

TABLE XXVI.—HEAT-TRANSMISSION COEFFICIENTS (U)*

Brick Walls		
	8-inch	12-inch
Plain walls—no interior finish	0.50	0.36
Plaster (½ inch) on walls	0.46	0.34
Plaster on wood lath—furred	0.30	0.24
Plaster on metal lath—furred	0.32	0.25
Hollow Tile Walls—Stucco Exterior		
	8-inch	10-inch
Plain walls—no interior finish	0.40	0.39
Plaster (½ inch) on walls	0.37	0.37
Plaster on wood lath—furred	0.26	0.26
Plaster on metal lath—furred	0.27	0.27
Concrete—Plain or Stucco Exterior		
	6-inch	10-inch
Plain walls—no interior finish	0.79	0.62
Plaster (½ inch) on walls	0.70	0.57
Plaster on wood lath—furred	0.39	0.34
Plaster on metal lath—furred	0.42	0.37
Hollow Concrete Blocks		
	8-inch	12-inch
Plain walls—no interior finish	0.56	0.49
Plaster (½ inch) on walls	0.52	0.46
Plaster on wood lath—furred	0.32	0.30
Plaster on metal lath—furred	0.34	0.32
Frame Construction		
Col. 1, interior—plaster on wood lath		
Col. 2, interior—plaster on metal lath	Col. 1	Col. 2
Wood siding, clapboards, or shingles on wood sheathing	0.25	0.26
Stucco	0.30	0.31
Brick veneer (on wood-frame work)	0.27	0.28
Frame Interior Walls		
Col. 1, plaster on wood lath		
Col. 2, plaster on metal lath	Col. 1	Col. 2
Plaster on one side of studding only	0.62	0.69
Plaster on both sides of studding	0.34	0.39

* By permission from "Guide" of American Society of Heating and Ventilating Engineers, 1934 ed.

TABLE XXVI.—HEAT-TRANSMISSION COEFFICIENTS (U).—(*Continued*)

Frame Floors and Ceilings

Col. 1, no flooring
Col. 2, yellow pine flooring on joists
Col. 3, maple or oak flooring on yellow pine sub-flooring

	Col. 1	Col. 2	Col. 3
No ceiling	....	0.46	0.34
Ceiling—plaster on wood lath	0.62	0.28	0.24
Ceiling—plaster on metal lath	0.69	0.30	0.25

Pitched Roofs

Col. 1, wood shingles on wood strips
Col. 2, asphalt or asbestos shingles; composition, slate, or tile roofing on wood sheathing

	Col. 1	Col. 2
No ceiling—rafters exposed	0.48	0.56
Ceiling—plaster on wood lath	0.29	0.32
Ceiling—plaster on metal lath	0.30	0.34
Windows, skylights, and panel doors (single glass)	1.13	

neglected except where some rooms are expected frequently to be unheated. An important example of this exception is the case of a church building where offices, etc., may be in use during the week while the adjoining auditorium is heated only on Sunday.

Gross wall area is the total area of the wall exposed to the inside air and includes windows, doors, etc. Net wall area is the gross wall area minus the area of windows, doors, etc. "Glass" area is taken as the full area of the window opening, and so includes the sash. Panel doors are considered as transmitting heat at the same rate as glass, and therefore their area is included in the glass area.

Linear dimensions are measured to the nearest inch, but for these calculations the nearest tenth of a foot may be used. Table XXVII may be used in making this conversion:

TABLE XXVII.—DECIMAL EQUIVALENTS IN FEET OF INCH DIMENSIONS

Inches	1			4	5		7	8	9	10	11
Decimals of a foot	0.1	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.75	0.8	0.9

Kitchen-heat-loss Calculation.—As an example of the use of equation (28) for transmission loss, consider the kitchen of the house shown in Fig. 206. The walls next to the pantry and study, the floor, and the ceiling may be neglected since they have heated spaces on both sides. The *south or rear wall* has a gross area of

$12.0 \times 8.7 = 104.4$ square feet (use 104 square feet).

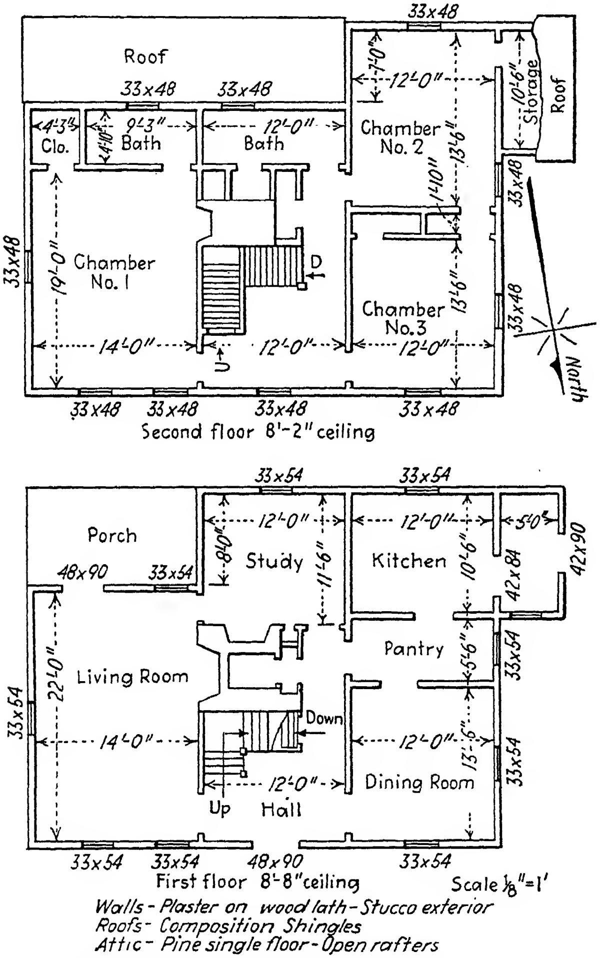


FIG. 206.—House plans showing first and second floors.

$$\text{Glass area} = \frac{33 \times 54}{144} = \frac{1{,}782}{144} = 12.4 \text{ square feet or use here}$$

2 feet 9 inches $\times$ 4 feet 6 inches $= 2.75$ feet $\times$ 4.5 feet $=$ 12.375 square feet.

Net wall area $= 104 - 12 = 92$ square feet.

Linear dimensions are used to the nearest tenth of a foot; but after the wall area is figured, the nearest square foot is used in the equation (28) for transmission. Since the heat loss through glass is comparatively high, use glass areas to the nearest tenth of a square foot.

Assuming an outside temperature of 0°F. and an inside temperature of 70°F., the temperature drop through the wall $(t_1 - t_0)$ is 70°F.

As shown in Fig. 206, the wall is plaster on wood lath with stucco exterior. Referring to Table XXVI under "Frame Construction," the coefficient U is given in the second line, column 1, as 0.30. Also at the bottom of the table the coefficient for glass is given as 1.13. Substituting in the transmission formula, the heat loss through the net wall area L_w (called the wall loss) is:

$$L_w = AU\,(t_1 - t_0).$$

$$92 \times 0.30 \times (70 - 0) = 1930 \text{ B.t.u. per hour.}$$

$$\text{Glass loss} = 12.4 \times 1.13 \times 70 = 980 \text{ B.t.u. per hour.}$$

$$\text{Total transmission loss} = 1930 + 980 = 2910 \text{ B.t.u. per hour}$$

The west wall of the kitchen is exposed to an unheated entry. Heat is transmitted from the kitchen through the dividing wall to the entry, and from the entry through its outside walls to the outdoor air. The temperature in the entry will be just high enough to make these two heat-transmission rates equal. In this case there is considerably more area for heat loss from the entry than for heat gain to the entry from the kitchen. Therefore, the entry temperature will be probably lower than the mean between 70° and 9°F. We shall assume that this temperature is 25°F., which will give a temperature drop through the kitchen wall of 70 − 25 = 45°. This wall is a "frame interior wall" with wood lath and plaster on both sides, and the coefficient F is given in Table XXVI as 0.34.

Therefore the heat loss through this west kitchen wall only may be calculated thus:

Gross wall area:	10.5×8.7	= 91.4 square feet.
Glass area:	3.5×7.0	= 24.5 square feet.
Net wall area:	$91.4 - 24.5$	= 66.9 square feet.
Wall loss:	$66.9 \times 0.34 \times 70$	= 1,592 B.t.u. per hour.
Glass loss:	$24.5 \times 1.13 \times 70$	= 1,250 B.t.u. per hour.
Total transmission loss		2,842 B.t.u. per hour.

The total transmission loss from the kitchen will be:

$$2910 + 2842 = 5{,}752 \text{ B.t.u. per hour.}$$

It should be noted that up to this point infiltration losses have not been considered.

Similar calculations must be made for each room in the house, taking into account any cases where ceilings or floors are exposed to unheated spaces or to outdoors. A great deal of time will be saved, and errors and omissions avoided, by arranging all the figures in some regular system. Tables XXVIII and XXIX show one form for such a system. These two tables might be combined by using a wide sheet of paper. The items for the kitchen and the study of Table XVIII are filled in to illustrate the use of these forms. (For the present, disregard column 6 in Table XXVIII and columns 4, 5, 10, 11, 12, 13, 14, and 15 in Table XXIX. These will be referred to later.)

The name of each room and a designation of each exposed wall are given in column 1. A separate line should be used for each exposed wall and for the room volume. Column 2 gives the number of windows and doors in the wall. If a given wall contains two windows of different size, and one or more doors, it is desirable to use an extra line for each different size. Column 3 shows the type of window or door. The abbreviation "D.H.W." indicates a double-hung window, and "Pan. door," a paneled door. In column 4 the dimensions of the *openings in the wall* are given, usually in inches, but feet or tenths may be used. Always be sure to indicate the units used. Columns 5, 8, and 9 need no comment.

In Table XXIX the items in columns 1, 2, and 3 are taken directly from columns 1, 9, and 5 of Table XXVIII. Knowing the materials and the type of construction, the coefficient for each wall, floor, ceiling, etc., is found in Table XXVI and should be entered in column 6. No column is provided for the glass coefficient since that is the same for all single-glazed windows or doors (1.13). Since most houses have some walls exposed to unheated spaces instead of to outside air, the temperature differences should be selected for each line and entered in column 7. The heat loss through the wall is calculated by multiplying the net area by the coefficient and by the temperature difference. This wall loss is entered in column 8, and the glass loss in column 9.

TABLE XXVIII.—ROOM DIMENSIONS FOR HOUSE (FIG. 206)

1	Windows and doors					Walls		
	Number	Description	Dimensions	Area, square feet	Feet of crack	Dimensions	Gross area, square feet	Net area, square feet
	2	3	4	5	6	7	8	9
Kitchen:								
S wall	1	D.H.W.*	33″ × 54″	12.4	17.25	12.0′ × 8.7′	104	92
W wall	1	Pan. door	42″ × 84″	24.5	21.00	10.5′ × 8.7′	91	66
Room	..	Room volume 1,096 cubic feet =			.....	12.0′ × 10.5′ × 8.7′		
Study:								
S wall	1	D.H.W.*	33″ × 54″	12.4	.....	12.0′ × 8.7′	104	92
E wall	..	....	....	....	.....	8.0′ × 8.7′	70	70
Ceiling	..	....	....	....	.....	7.0′ × 12.0′	84	84
Room	..	Room volume 1,200 cubic feet =			.....	12.0′ × 11.5′ × 8.7′		

* Double-hung window.

TABLE XXIX.—RADIATION REQUIRED FOR KITCHEN AND STUDY (FIG. 206)

1	Net wall area, square feet	Glass area, square feet	Feet of crack	Infiltration cubic feet per hour	Coefficient	Temperature difference	Heat loss B.t.u. per hour: Wall loss	Glass loss	Infiltration loss	Total loss	Exposure factor	Gross loss	Radiation, square feet: As calculated	As selected
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Kitchen:														
S wall	92	12.4	17.25	1900	0.30	70	1930	980	....	2910				
W wall	66	24.5	21.00	2320	0.34	45	1592	1250	2920	5762				
Room	..	....	.....	....	....	..	3522	2230	2920	8672	1.00	8672	34	
Study:														
S wall	92	12.4	17.25	1900	0.30	70	1930	980	2390	5300				
E wall	70	....	.....	....	0.30	70	1470	....	....	1470				
Ceiling	84	....	.....	....	0.62	35	1820	....	....	1820				
Room	..	....	.....	....	....	..	5220	980	2390	8590	1.00	8590	36	

It may be well to summarize the accuracy to which the various items should be carried. All linear dimensions are measured and recorded to the nearest inch, or the nearest tenth of a foot. Wall areas are recorded to the nearest square foot. Heat-loss values are recorded to the nearest 10 B.t.u. For example, the wall loss for the south wall of the kitchen actually figures 1932 B.t.u. per hour, but 1930 is used.

Totals of each heat-loss column for each room should be entered in the line marked "Room." This provides for a cross check of the additions, which are made later and entered in column 11.

A study of the dimensions on the plan of Table XXVIII will show that the total length of the second floor is greater than that of the first. This indicates an "overhang" which is not uncommon in certain types of houses. In this particular case, the south wall of chamber 2 is directly over the south wall of the kitchen, so that the overhang is all on the front of the house. A further study of the plan will show that the room marked "Study" extends 7 feet beyond the south wall of the bathroom which is above it. Therefore a part of the study ceiling (an area 7 by 12 feet) is directly under an exposed roof. Theoretically, the heat loss through this ceiling should be figured by calculating a combined coefficient for the ceiling and the roof, taking into account the fact that the slope of the roof results in a roof area greater than the ceiling area. However, it will be sufficiently accurate to take a ceiling coefficient of 0.62 (plaster on wood lath, no floor above). See Table XXVI (page 303) and assume that the temperature of the space between the ceiling and the roof is 35°F.

In figuring the heat loss for the second floor, the closet at the south-east corner of chamber 1 should be considered as an unheated space. The closet between chambers 2 and 3 has so little outside exposure that its temperature will not be much less than that of the rooms. Since it has a connecting door with each of the chambers, one-half its exposed wall should be added to the west wall of each of these chamber walls. If this closet opened only into one room, its entire exposure should be added to that of the room to which it connected. The attic, which extends over the entire second floor, is unheated.

Infiltration Loss.—In addition to the heat loss by actual transmission through the walls, a considerable amount of heat must be used to warm the air which leaks into the building. The

amount of this air may be estimated, approximately, by assuming a certain number of *air changes* per hour for each room. The assumption of "one air change per hour" means the assumption that the cubic feet of air leaking in per hour is equal to the volume of the room. The values usually assumed are as follows:

	Air Changes per Hour
Rooms, 1 side exposed	1
Rooms, 2 sides exposed	1½
Rooms, 3 or 4 sides exposed	2
Entrance halls	2 to 3

These values are the result of experience rather than experimental data.

The *crack-leakage method* gives a more logical and accurate result. It is obvious that most of the air leakage is caused by the wind forcing air through the cracks around windows and doors. A great deal of research has been done to determine the amount of air that will leak through a crack 1 foot long, of various widths, under various wind velocities. For a given window, the length of crack is easily found from the window dimensions. For a double-hung window this is the distance around the sash plus the length of the meeting rail. In other words, it is twice the total height of the sash plus three times the width. For example, the first-floor windows of Table XXVIII are 54 inches high and 33 inches wide. Therefore, the crack length is

$$2 \times 54 + 3 \times 33 = 207 \text{ inches or } 17.25 \text{ feet.}$$

The wind velocity usually assumed is the average velocity shown by the U. S. Weather Bureau reports for the months of December, January, and February, but never less than 15 miles per hour.

The "Guide" published by the American Society of Heating and Ventilating Engineers gives the data similar to that in

TABLE XXX.—INFILTRATION AT DOUBLE-HUNG WOOD WINDOWS

Condition of Window	Volume of Infiltration Air per Hour, per Foot of Crack
1. Average window 1/16-inch crack	39
2. Same weather-stripped	23
3. Poorly fitted window 3/32-inch crack	110
4. Same weather-stripped	34

Table XXX for infiltration for *double-hung wood-sash* windows, from a 15-mile wind.

Since most houses have little or no provision for humidification, wood sash are exposed to very dry air and so are likely to shrink, especially in cold weather. The higher values in the table should ordinarily be used unless there is reason to believe that there is fairly good humidification and that the windows are well fitted. Storm sash will reduce the leakage through a poorly fitted window about 50 per cent. With well-fitted windows, or with weather strips, storm sashes do not seem to have much effect on the infiltration loss.

Air infiltration through *casement windows* or through *doors* may be assumed as *twice* that through double-hung windows, per foot of crack.

The data given for crack leakage are based on experiments with the wind blowing at right angles with the wall in which the window is located. If the room has openings on more than one side, it is obvious that the wind cannot blow directly against more than one side at a time. Therefore it is usual to consider the crack in the side having the greatest crack length, but *never less than one-half the total crack length of all the openings in the room.*

Referring to the kitchen of Table XXVIII the south wall has one window with a crack length of 17.25 feet, giving a probable leakage of

$$17.25 \times 110.5 \text{ (Item 3 in Table XXX)} = 1{,}906 \text{ cubic feet per hour.}$$

The west wall has one door with a crack length of 21.0 feet. Since this door opens into a vestibule, it may be assumed that the leakage per foot of crack will be the same as, rather than double, that for a window. Therefore the leakage for this wall will be:

$$21.0 \times 110.5 = 2{,}320 \text{ cubic feet per hour.}$$

The total leakage for the room will be that for the greatest side, that is, 2,320 cubic feet per hour.

It requires 0.018* B.t.u. to raise the temperature of 1 *cubic foot* of air 1°F. Therefore with a temperature difference of 70°F. each cubic foot of air leakage will absorb

* At 70°F. the weight of a cubic foot of air is 0.075 (Table p. 45) and the specific heat is 0.24. Heat required to raise temperature of one cubic foot of air at 70°F., one degree F. is 0.075×0.24 or 0.018 B.t.u.

$$0.018 \times 70 = 1.26 \text{ B.t.u.}$$

The infiltration heat loss from the kitchen will be

$$2{,}320 \times 1.26 = 2920 \text{ B.t.u. per hour.}$$

This is entered in Table XXIX in column 10 on the line of the west wall. The values for column 11 are obtained by totaling the values in columns 8, 9, and 10. The south-wall loss is 2,910 and the west-wall loss 5,180 and the total loss for the room is the sum of these two or 8,090 B.t.u. per hour. A check on the addition is made by adding the room totals for each of the columns 8, 9, and 10 (2,910 + 2,230 + 2,920).

Exposure Factors.—It is obvious that the conditions of exposure will have an effect on the heat loss from any given wall. The nearness and the location of other buildings, hills, trees, etc., the direction of the prevailing winds, and the radiant heat from the sun should be considered. Unfortunately there are very few accurate data on which to base numerical calculations of these effects. The usual practice is to increase the heat-loss values, computed as outlined above, by certain assumed percentages. The coefficients for transmission losses and the data on infiltration losses given above are all based on a wind velocity of 15 miles per hour. Higher wind velocities often occur, and in the colder weather are more likely to be in the direction of the prevailing winds or somewhat north of that direction. In Boston, the prevailing winds (from December to February) are from the west. Therefore it is usual to increase the heat-loss figures for walls exposed to the north, northwest, or west. As a rule, velocities of more than 15 miles per hour from other directions are accompanied by temperatures well above zero.

Because low temperatures and high winds may occur on cloudy days or at night, it is the usual practice to take no account of the heat of direct radiation from the sun. However, it seems reasonable to assume that some *sun effect* is present even on dark days. Also it is true that the heat absorbed from direct sun rays is, to a certain extent, stored in the building structure and reduces the necessary rate of heat supply for some hours after sunset.

While authorities differ as to the actual values of *exposure factors*, the following rules may be used with reasonable safety:

1. Heat loss is increased about 10 per cent for rooms exposed to the north, northwest, or west.
2. If the building is isolated with no wind protection within 200 feet, the heat loss is increased 15 per cent for north, northwest, and west winds.
3. In case of extreme exposure as, for example, on a hill top with no nearby wind protection, the increase may be as much as 20 per cent.

In thickly settled communities, a building undoubtedly benefits, to some extent, by the heat lost from the surrounding buildings. However, there are no data as to the amount.

The exposure factors entered in column 12 (Table XXIX) provide for the exposure allowances. If the allowance is to be 10 per cent, the total heat loss of column 11 is multiplied by 1.10 and the result entered as gross heat lost in column 13. Under the rules given above, the kitchen of Table XXVIII might be expected to have an exposure factor of 1.10 since it has one exposure to the west. However, the entry protects this whole western wall of the kitchen so that the exposure factor is 1.00, that is, no exposure allowance is to be considered.

Required Radiation.—The gross heat loss for each room recorded in column 13 (Table XXIX) is the maximum rate, in B.t.u. per hour, at which heat must be supplied to maintain the desired temperature. Since one rated square foot of steam radiation will supply 240 B.t.u.* per hour, the size of the radiator, or radiators, can be found by dividing the gross heat loss by 240. This result is entered in column 14 for hot-water radiation; the divisor is 160.†

The actual radiator to be used will depend on the local conditions in the room. If possible, the radiator should be placed under a window, and so its height is limited by the height of the window sill. In some cases a long narrow radiator might be preferable to a short wide one, or vice versa. The sectional construction of modern radiation allows a wide variety of choice. For example, in Table XXIX the study requires 36 feet of steam radiation. A study of a manufacturer's catalogue indicates that any of the radiators listed in Table XXXI might be used.

These are only a few of the possible combinations from which selections might be made. It will be noticed that the rated areas of the examples given vary slightly from the calculated value of

* See equivalent radiation, p. 293.

† See page 292.

36 square feet. Therefore, the height, the number of tubes, the number of sections, and the rated area of the radiator selected should be entered in column 15 of Table XXIX.

TABLE XXXI.—CAST-IRON SECTIONAL RADIATORS

Height, inches	Number of tubes	Number of sections	Length, inches	Square radiation, feet
32	3	12	30	36
23	3	18	45	36
38	4	9	22½	38¼
26	4	14	35	38½
32	6	7	17¼	35

If a gravity warm-air heater is used, the gross heat loss of 17,262 B.t.u. (column 13, Table XXIX) should be divided by 111, 166, or 200 respectively for the first, the second, or the third floor. These values, are then entered in column 14*a* as the square inches of leader-pipe area. The diameter of the *leader* pipe, selected as explained on page 280 is then entered in column 15*a*.

In many cases much better results can be obtained by providing two or more small radiators for a room instead of one large one. In this case the separate determination of the heat loss for each wall enables the designer to proportion the total radiation among the separate units so that a uniform temperature can be maintained in the different parts of the room.

Application to Oil-burner Practice.—So far, in this chapter, the calculation of heat loss has been discussed from the viewpoint of the heating-system designer. However, the same procedure should be followed in the survey for an oil-burner installation. In the latter case the details of the radiators actually used should be entered in column 15 (Table XXIX) when the survey is made. Then, when the calculations are completed, the actual radiation used can be compared with that required, as in column 14. Any great differences should be investigated and corrected. If the required changes cannot be made, all the facts should be submitted to the owner *in writing* so that future misunderstandings may be avoided.

In most cases a radiator that is too large for a particular room is almost as undesirable as one that is too small. The main objection to oversize radiators is that the first cost will be larger

than necessary; but if the system is already installed, there is little to gain and probably much to lose by making changes. However, if one or more radiators are too large while the rest are correctly sized, uneven heating will result. This is especially troublesome if the oversize radiator is in the room where the thermostat is located. In any case, overheating of any room or rooms increases the heat loss and therefore the fuel consumption.

Approximate Methods of Heat-loss Calculations.—"Rule-of-thumb" methods are satisfactory for checking most heating calculations for buildings. One of these is the Mills' "2-20-200" rule, which, as stated in *terms of square feet of direct steam radiation R* (page 293) is given by the following equation:

$$R = \frac{G}{2} + \frac{W}{20} + \frac{V}{200}$$

where G = area of glass (and doors) in room, square feet.
W = *net* area of exposed walls in room, square feet.
V = volume of room, cubic feet.

For a *hot-water direct-radiation system*, the number of square feet of radiation surface is obtained by multiplying the value of R as found by the above equation by 1.8 to obtain the equivalent radiation surface.

Carpenter's Approximate Method of Heat-loss Calculation.—Another rule, known as "Carpenter's," may be stated by the following equation where H the heat loss per hour in B.t.u. (page 19) is:

$$H = (0.02nV + G + 0.25W)(t_i - t_o) \qquad (30)$$

where n = number of air changes per hour required in the room.
V = volume of room, cubic feet.
G = area of glass (and doors) in room, square feet.
W = *gross* area of wall in room, square feet.
t_i = inside temperature of room, °F. (usually 70°F. for such calculations).
t_o = outside temperature of room, °F. (usually 0°F. for eastern and central states).*

* A temperature of −18°F. and subzero temperatures for 30 consecutive hours were recorded in Boston during the winter of 1933–1934, but there is no reason to believe that such low temperatures will be repeated in frequent years.

These rules came into use many years ago when few, if any, accurate data on heat loss were available.

Comparison of Calculated Results.—For comparable results, the size of the steam radiator required for a typical room was calculated by Professor De Witt Taylor from data given below by both rules. Mills' rule gave approximately 36 square feet and Carpenter's rule, 44 square feet. Each of equations 30 and 31 gives a different proportionate "weight" to the wall and the glass areas. Similar data for some other room might, therefore, have given quite different comparative results. Professor Taylor states that Mills' rule will probably give a more accurate total when applied to the building as a whole than if applied to each room, with the results totaled. However, this leaves out information as to the relative sizes of the different *radiators*, which is just as important as the total, so that on this account the method is useful mainly for checking.

Since 1 square foot of "unpainted" steam radiation gives off 240 B.t.u. per hour, Mills' rule may be written as follows:

$$H = 240\left(\frac{G}{2} + \frac{W}{20} + \frac{V}{200}\right) = 120G + 12W + 1.2V \quad (31)$$

where H = heat requirement per room, B.t.u. per hour.
G = glass area, square feet.
W = net wall area, square feet.
V = volume of room, cubic feet.

It will be observed that the three terms of the right-hand side of this equation represent respectively (1) glass loss, (2) wall loss, and (3) air-infiltration loss.

A "transmission" equation for the glass loss only may be written in the following terms:

$$H_g = GF_g(t_i - t_o) \quad (32)$$

where H_g = heat loss through glass, B.t.u. per hour.
G = glass area, square feet.
t_i = inside room temperature, usually assumed as 70°F.
F_g = glass-transmission coefficient.
t_o = temperature of outside air, usually assumed as 0°F.
$t_i - t_o$ = temperature difference for 70°F. inside and 0°F. outside temperatures = 70°F.

Combining the term in Mills' rule (equation 29) for glass loss with the right-hand member of equation (32),

$$120G = GF_g \times 70$$
$$F_g = {}^{120}\!/_{70} = 1.71$$

Since the experimental value for the glass coefficient is 1.13 (page 307), it is evident that Mills' rule will give too large a value for the heat loss through glass.

In the same way the coefficient for the wall, which would give the same heat-loss value as Mills' rule, can be shown to be 0.171. An inspection of the values in Table XXVI shows that the lowest wall coefficient given is 0.25. This rule, therefore, gives a heat loss through walls that is much too low.

If we compute the infiltration loss by the "air-change" method, the formula may be written:

$$H_a = 1.26nV \tag{33}$$

where H_a = loss due to infiltration, B.t.u. per hour.
n = number of air changes per hour.
V = volume of room, cubic feet.

Writing this as equal to the Mills-rule value for infiltration we get:

$$1.26nV = 1.2nV$$

and therefore

$$n = \frac{1.2}{1.26} = 0.95$$

Since the generally accepted value for the *average* number of air changes is 1.5, it is evident that Mills' rule gives too small a value for this item. Mills' rule is based on a temperature difference of 70°F. between the air on the two sides of the wall. If any other temperature difference is to be used, the result should be multiplied by the temperature difference and divided by 70. This applies particularly to walls, floors, or ceilings separating heated from unheated spaces.

To summarize, Mills' rule overestimates the glass loss and underestimates the wall and infiltration losses.

Carpenter's rule may be arranged as follows:

$$H = 0.02nV(t_i - t_o) + G(t_i - t_o) + 0.25W(t_i - t_o) \tag{34}$$

The first term gives the infiltration loss. Here the figure 0.02 is used instead of 0.018 for the heat required to raise the tempera-

ture of one cubic foot of air 1°F. (page 312). With an intelligent selection of the value of n, the infiltration loss should check reasonably well with other methods.

The second term, giving the glass loss, evidently assumes a glass coefficient of 1.00 as compared to the standard coefficient of 1.13. However, the *gross* wall area is used in the third term. This is equivalent to computing the glass loss twice, with a coefficient first of 1.00 and second of 0.25; this amounts to a single computation with a coefficient of 1.25, which is high. The wall coefficient of 0.25 corresponds to that given in Table XXVII for a frame wall with wood lath and plaster, and wood siding, clapboards, or shingles on wood sheathing. *For all other uninsulated walls this coefficient is too low.*

Carpenter's rule, then, will give a fairly good value for the infiltration loss, the equivalent of a high value for glass loss, and the equivalent of a low value for wall loss, except in the case of the particular wall constructions named in the preceding paragraph. If one does use the Mills or Carpenter rules, one must include floors or ceilings exposed to cold or unheated spaces.

A number of tables and diagrams have been published to reduce the labor of computation. For example, the Heating and Piping Contractors' National Association has prepared a "Standard Radiation Estimating Table." This gives the number of square feet of wall, roof, floor, glass, etc., which require various amounts of direct-steam radiation. The area of the wall, etc., is computed in the usual way, and the nearest number to this located in the table in the column corresponding to that particular wall construction. On the same line with this the square feet of radiation is found in the first column of the table. The table is based on the coefficients determined by the American Society of Heating and Ventilating Engineers and gives results that check closely with the methods of accurate calculations. Tables have been prepared for various cities, taking account of the local temperature conditions. A set of exposure factors is given based on the local prevailing wind conditions. The only labor saved by the use of this table is the multiplication of the area, coefficient, and temperature difference, the product being divided by 240* to find the radiation surface.

* See p. 292 for definition of equivalent radiation surface.

Survey Methods.—If the heat loss is to be calculated with accuracy for a new building, the dimensions required can be obtained by scaling the architect's plans. If the building is old, such plans are usually not available and the dimensions must be obtained from a survey. A plan of each floor should be sketched, and *all* required dimensions marked on it.

Sketch plans should be made freehand, using a single line to represent a wall. No attempt need be made to work to scale. However, some care should be used to keep the various dimensions reasonably proportionate. A field sketch is not a finished drawing, but it should not be so rough that it is not clear. Try to work with the idea that some one who had never seen the building could make a complete heat-loss calculation from your sketch and figures.

While satisfactory sketches can be made on plain paper, it is much easier to work on quad-ruled or cross-sectional paper. The ruled lines act as guides so that it is easy to show straight walls parallel and at right angles to each other. Rulings of 8 or 10 squares to the inch are the most satisfactory. It is unnecessary to use what is called "plotting" paper. This is ruled very accurately and is therefore expensive. Whatever the form of paper used, it should be made up into a pad with a stiff cardboard back. Sketching on a single sheet of paper is slow, awkward work.

In general it is best to draw the exterior outlines of the whole house while outside. Then fill in the partition lines, going systematically from one room to the next. Modern houses are usually fairly simple in arrangement. In the older buildings all sorts of unexpected closets, passages, etc., are likely to be met. Sometimes a room has no connection with a hall but must be reached through another room. It is very easy to overlook such a space entirely.

In each room measure and record on the sketch the length of each outside wall. If the room has only one exposed wall, the inside walls should also be measured so that the overall dimensions of the house may be checked. If the room is not a simple rectangle, it is best to measure the length of every straight portion of the walls. Sometimes what appears inside a room as a straight unbroken wall is partly exposed to the outdoors and partly to another room. The east wall of the house shown in Fig. 206

is an example of this. Eight feet of this wall is exposed to the exterior, and the balance to the living room. If there were no door between these rooms, this fact would not be apparent to anyone standing in the study. Obviously the length of each

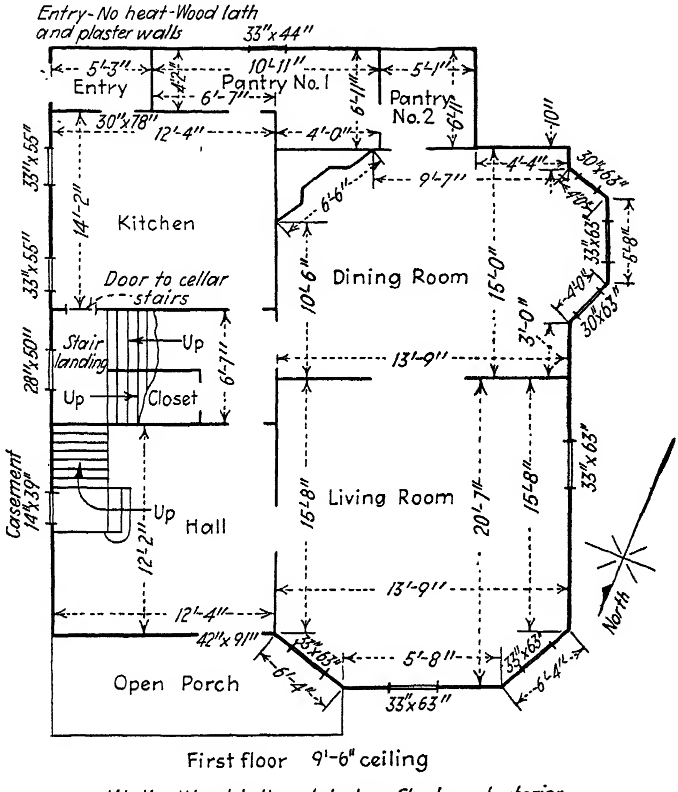


FIG. 207.—House plan showing one floor only.

section of the wall must be determined. Other examples are the east and the west walls of chamber 2 in the same figure.

An example of a sketch plan of the first floor of an actual house is shown in Fig. 207. Breaks in the wall lines indicate doors, and the dimensions of those opening outside or into unheated spaces are given in inches. Windows are indicated by two cross lines through the walls. The dimensions are those of the opening

in the wall. Where there is no special designation, a double-hung window is understood. A casement or special form of window should be so marked and sufficient information given so that the length of the crack around the window may be determined.

Room measurements, of course, are made inside from wall to wall. Enough measurements should be made so that the overall dimensions of the house can be totaled from two sets of rooms. In making these totals, partitions may be assumed to be 6 inches thick. For example, in Fig. 207 the total length of the house from front to back may be checked as follows:

East Side		West Side	
Hall	12′ 2″	Living room	15′ 8″
Partition	0′ 6″	Partition	0′ 6″
Passage	6′ 7″	Dining room	15′ 0″
Partition	0′ 6″	Partition	0′ 6″
Kitchen	14′ 2″	Pantry 2	6′ 11″
Partition	0′ 6″		
Entry	4′ 2″		
Total	38′ 7″	Total	38′ 7″

Similar checks should be made across the house through the hall and the living room, the kitchen and the dining room, and the entry and the pantries. These checks should be made before leaving the house so that any errors may be found and corrected.

Partitions are not exactly 6 inches thick, and no plastered wall is a true plane surface. Therefore, if the totals of two or more sets of measurements check within 2 or 3 inches, the results may be accepted as correct. An error of 3 inches in 30 feet is an error of less than 1 per cent.

Special care should be taken to locate, and show the dimensions of floors or ceilings exposed to roofs or unheated spaces. Such cases are usually not apparent when the observer is inside a finished room. For example, in the study of Fig. 206 there is nothing in the room to show that part of the ceiling is exposed to an unheated space under a roof. A comparison of the overall dimensions of the various floors will usually indicate the presence of such exposures. A second inspection of the outside of the house, after the sketches are completed, will also help. However, unheated spaces under eaves, etc., may not be apparent from outside or inside. This is especially likely in houses of the "English" style, which have been so popular in recent years.

If the outside inspection shows any irregularities between floors (such as overhangs or setbacks) the relative positions of the different floor plans should be definitely indicated. Referring again to Fig. 206 the main east wall of the second floor is directly above that of the first floor, and the back wall of chamber 2 is over the back wall of the kitchen. From this information and the dimensions, the second-floor overhang can be located and also the cold ceiling and the floor exposures in study and bathroom calculated. Do not use inside chimneys to locate relative floor positions. Such chimneys are frequently offset or changed in size between floors and therefore may be misleading.

One of the most troublesome cases is where a room is cut up by sloping roofs and dormer windows. In such cases the plan sketch should show the outlines of the room at the floor line and separate sketches of vertical sections should be made. The location of these sections should be shown on the plan, and the dimensions of each wall, ceiling, or floor surface indicated. It is better to make unnecessary sections and show unneeded dimensions than to omit one or more essential items.

Be sure to show on the sketches the direction of the points of the compass and to measure and record ceiling heights.

In making surveys, the basement or the cellar is often neglected. If the house is on level ground and the first floor near the ground, this may cause no trouble as the heat from the boiler and the steam mains will keep the cellar reasonably warm. If, however, one or more cellar walls extend much above the ground level and if there is much glass in windows and doors the heat loss may be quite large. In troublesome cases a sketch of the cellar should be made and the heat loss computed.

It is usual to proportion first-floor radiators on the assumption that the cellar is heated. Even if the radiation is increased to provide for the heat loss through the floor to a cold cellar, it may be that with an oil burner this trouble will be greater than with coal, owing to intermittent operation. The fact that cellar ventilation is necessary to provide air for combustion increases this trouble.

Insulation of Steam and Hot-water Pipes in Cellar.—It is not good practice to heat the cellar by removing or omitting the insulation of the steam mains. This will interfere with the circulation to the radiators and so spoil the operation of the whole

system. If heat is needed in the cellar, it should be provided by radiators, proportioned and located with the same care as those in the other parts of the house.

Cold Rooms.—Some cellars have spaces partitioned off to be used as "cold rooms" for vegetable storage. Complaints about cold floors in the rooms above are likely to be received. The ceilings over such places should be insulated and extra radiation provided in the rooms.

Sun Rooms.—Special attention should be given to sun rooms. The relatively large glass area will indicate a high transmission heat loss which will be taken care of in the normal calculation. However, the infiltration loss is sure to be excessive. In many cases the windows are not so carefully fitted as in the rest of the house, and in any case the crack length is greater than normal. If infiltration is figured by the air-change method (page 316), four, or in extreme cases five, changes of air per hour should be assumed.

In many houses, sun rooms extend beyond the main foundation walls and so have no excavation underneath. In this case the floor should be considered as exposed to outdoors. Another trouble from this construction is that the sun-room foundations are often too light. This allows small settling, which results in cracks in walls and so increases the air leakage. Serious heat losses may occur in such cases. It is a good plan to put a level on the sun-room floor. Any marked slope away from the main body of the house is an indication of some kind of structural failure.

Even with adequate radiation, a sun room is likely to be a source of complaint when heated by an oil-burner installation that is thermostatically controlled from other rooms. The comparatively high rate of heat loss causes a quick temperature drop when the oil burner shuts down so that the sun room may become several degrees cooler than the rest of the house before the thermostat again demands heat.

CHAPTER X

ESTIMATING SAVINGS FROM HEAT INSULATION OF WALLS AND ROOF

Dimensions of Residence.—The building for which cost and expense savings are to be calculated when its walls are filled with rock-wool insulation is a residence of more than average size measuring 40 by 25 feet and 20 feet high at the eaves of the roof. There are first, second, and third floors (attic rooms) which are finished in plaster and are to be heated, with the peak of the roof 8 feet 4 inches above the eaves.

Lowest and Base Temperatures.—At the location of the residence for which this calculation is to be made, the lowest temperature from U.S. Weather Bureau records for the last 10 years is -24°F. The *base temperature** is ordinarily taken as 15°F. *above* the lowest record in the last 10 years or is $-24 + 15 = -9$°F. This base temperature is used only for the *design* of the heating system.

Average Outside and Inside Temperatures.—For the location of this residence, the average *outside temperature* from the U. S. Weather Bureau records is approximately 40°F., "*during the period* from October 1 to May 1." This temperature is used in calculating the *average heat losses.* The inside (indoor or room) temperature is commonly assumed to be 70°F. in practically all American designing of heating equipment. In this case the *temperature difference* between average inside and outside air conditions is, therefore, $70 - 40 = 30$°F.

Average Wind Velocity and Prevailing Wind Direction.—The records of the U. S. Weather Bureau show again that the average wind velocity in December, January, and February at the location of this residence is approximately 9 miles per hour. Coefficients of heat transmission U used here are based on a wind velocity of 15 miles per hour for outside surfaces and 0 miles per hour for inside, or nearly still air. The rate of 15 miles per hour

* Base temperature is the minimum temperature used in heating calculations, as on p. 302.

will be used for wind-velocity transmission coefficients and actual average wind velocity (9 miles per hour) for *infiltration* (page 302), since these are calculations where wind velocity is really an important consideration.

Heating Period.—The duration of the period when the residence is heated throughout is assumed to be about seven months (October 1 to May 1), say 210 days, and this heating is further assumed to continue for 17 hours per day; there being 7 hours per day when little heat will be used.*

Thermal Conduction of Building Materials in Walls.—Table XXXII shows the derivation of the heat-transmission coefficient U

TABLE XXXII.—HEAT-TRANSMISSION COEFFICIENTS FOR WALLS

	Values of C	Values of $1/C$ for calculation of R for uninsulated wall	Values of $1/C$ for calculation of R for insulated wall
1. Outer surface (f_o)	6.00*	0.167	0.167
2. Brick (face or veneer)	2.30†	0.435	0.435
3. Wood sheathing	0.82‡	1.220	1.220
4. Air space (3⅝ inches thick)	1.10	0.908	0.908
5. Rock wool (3⅝ inches thick)	0.0745‖		13.420
6. Plaster on wood lath	2.50§	0.400	0.400
7. Inner surface (f_i)	1.65	0.606	0.606
8. Overall heat "resistance" $R(=1/U)$		3.736	17.156
9. Heat-transmission coefficient U		0.27	0.062

* Table I, A.S.H. and V.E. "Guide," 1936, p. 512.

† Called in Table II (A.S.H. and V.E. "Guide," 1936, p. 107) "brick face." For face or veneer brick the heat conductivity is 9.20 B.t.u. per hour per square foot per degree Fahrenheit per inch thickness or for 4-inch thickness is 9.20 ÷ 4 or 2.30 B.t.u.

‡ Called in Table XX "1-inch thickness for sheathing and building paper."

§ Called in Table XX "wood lath and plaster."

‖ This value is based on value of C of 0.27 per inch of thickness.

for the walls of a residence (data from A.S.H. and V.E. "Guide," and other sources) calculated by the following formula, where

$$U = \frac{1}{R} = \frac{1}{\dfrac{1}{C_1} + \dfrac{1}{C_2} + \dfrac{1}{C_3}, \text{ etc.}}$$

* Some tests show that there is no advantage in regard to fuel economy in allowing a building to cool off at night, especially if the outside walls and roof are insulated (page 283).

Wall Areas and Heat Losses.—The areas of wall surfaces may be calculated most easily for the average type of residence by reference to floor-plan and elevation drawings. If such drawings (usually blueprints) are not available, sufficiently accurate wall areas may be calculated from rough measurements made with a steel or muslin tape. The general method is to calculate the total outside surface and deduct the chimney areas and the areas of windows and doors to obtain the *net wall area* to be insulated. In the residence used for this calculation, the following data were obtained:

Total wall area	2,808 square feet
Chimney area (to be deducted)	100 square feet
Wall area less chimney area	2,708 square feet
Windows and doors (to be deducted)	428 square feet
New wall area to be insulated	2,280 square feet

Heat loss through walls when *uninsulated* = net wall area × heat-transmission coefficient × temperature difference, or net wall area × U × $(t_i - t_o)$

= 2,280 × 0.27* × (70 − 40)

= 18,468 B.t.u. per hour

Heat loss through walls when *insulated* = 2,280 × 0.062† × (70 − 40)

= 4,241 B.t.u. per hour

* Item 9 in Table XXXII, second column.

† Item 9 in Table XXXII, third column.

Window and Door Areas and Heat Losses.—The total areas of doors (thin wood and glass paneling) in the residence is 146 square feet and of windows (double-hung, single-thickness glass) is 282. The heat-transmission coefficient for windows and doors of this type is assumed to be 1.13 (A.S.H. and V.E. "Guide." 1936, page 125, footnote).

Heat loss through windows = 282 × 1.13 × (70 − 40)	=	9,560 B.t.u. per hour
Heat loss through doors = 146 × 1.13 × (70 − 40)	=	4,949 B.t.u. per hour
Total heat loss through windows and doors		14,509 B.t.u. per hour

Roof Areas and Heat Losses.—The total roof area (actual surface covered by roofing) is 1,202 square feet. The calculation

of the heat-transmission coefficient U is made with the following data:

TABLE XXXIII.—HEAT-TRANSMISSION COEFFICIENTS FOR ROOF

	Values of C	Values of $1/C$ for calculation of R for uninsulated roof	Values of $1/C$ for calculation of R for insulated roof
Outer surface		0.167	0.167
Rigid asbestos shingles		0.167	0.167
Wood sheathing		0.781	0.781
Air space (3⅝ inch thick)		0.908	
Rock wool (3⅝ inch thick)			13.420
Plaster on wood lath		0.400	0.400
Inner surface		0.606	0.606
Overall heat "resistance" $R = 1/U$		3.029	15.541
Heat-transmission coefficient U		0.33	0.064

* See footnote page 326.

Heat loss through uninsulated roof = area × heat-transmission coefficient × temperature difference, or area × U × $(t_i - t_o)$ = 1,202 × 0.33 × (70 − 40) = 11,900 B.t.u. per hour

Heat loss through insulated roof = 1,202 × 0.064 × (70 − 40) = 2,308 B.t.u. per hour

TABLE XXXIV.—HEAT-TRANSMISSION COEFFICIENTS FOR FLOORS

	Values of C	Values of $1/C$ for insulated floor
Upper surface*	1.65	0.606
1 3/16-inch oak-top flooring	1.15†	0.707
1 5/32-inch yellow-pine subflooring	0.80†	0.977
Lower surface*	1.65	0.606
Overall heat "resistance" $R = 1/U$		2.896
Heat-transmission coefficient U		0.34

* Upper- and lower-surface-heat conductances C are the same on both sides of the floor for the reason that both sides are protected from *outside* exposure.

† Values given are per inch of thickness.

Area and Heat Losses of Basement Floor.—The area of the floor over the basement is approximately the area of the basement-floor-plan area or 40 by 25 feet = 1,000 square feet. Basement temperature is assumed to be 50°F. and the temperature of the floor of the first-floor rooms is 65°F.* The temperature difference between the two sides of the floor is 65 − 50 or 15°F. The data for calculating the transmission coefficient U in this case are given in Table XXXIV.

Heat loss through basement floor = area ×
heat-transmission coefficient × temperature difference, or
area $\times\ U \times (t_1 - t_2) = 1{,}000 \times 0.34\ (65 - 50) =$
5,100 B.t.u. per hour.

Infiltration-heat Loss.—The amount of air leakage *per foot of the cracks* around the average window that is not weather-stripped (including "frame" leakage) for wind velocity of 9 miles per hour, is 18.9 cubic feet of air per hour.† The total length of the window cracks (page 311) in the residence is 380 feet.

The heat loss occasioned by this air infiltration through *window cracks* is the total length of window cracks × air leakage per foot of crack × the weight of a cubic foot of air‡ × the specific heat of air§ × the temperature difference between the outside and inside air. The product of these quantities is,

$18.9 \times 380 \times 0.075 \times 0.24 \times (70 - 40) = 3{,}877$ B.t.u. per hour.

Infiltration through door cracks is usually taken as twice‖ the leakage through windows. The total length of *door cracks* in this residence is 155 feet.

Heat loss by infiltration through door cracks is

$18.9 \times 2 \times 155 \times 0.075 \times 0.24 \times (70 - 40) =$
3,165 B.t.u. per hour.

Total infiltration losses through windows and doors is 7,042 B.t.u. per hour.

* It is unnecessary to calculate heat losses for rooms that are supposed to have the same temperature on both sides, as the heat loss is obviously zero.

† A.S.H. and V.E. "Guide," 1936, p. 135.

‡ An average value of the density or weight of a cubic foot of air is about 0.075 pound. Specific heat of air at ordinary temperatures is 0.24.

§ "Elements of Engineering Thermodynamics," by Moyer, Calderwood, and Potter, 5th ed., 1933, p. 169.

‖ A.S.H. and V.E. "Guide," 1936, p. 134.

TABLE XXXV.—AVERAGE TOTAL HEAT LOSSES IN RESIDENCE

	With insulation in walls and roof, B.t.u. per hour	Without insulation, B.t.u. per hour
1. Walls...........................	4,241	18,468
2. Roof............................	2,308	11,900
3. Basement floor..................	5,100	5,100
4. Windows and doors (heat transfer)	14,509	14,509
5. Window and door infiltration.....	7,042	7,042
Total heat loss for comparison.....	33,200	57,019

Reduction of heat losses because of insulation in walls and roof is $57{,}020 - 33{,}200 = 23{,}820$ B.t.u. per hour, or on a yearly basis, $23{,}820 \times 3{,}570^* = 85{,}037{,}400$ B.t.u.

Fuel saving is $23{,}820 \div 57{,}020 = 0.418$, or 41.8 per cent.

Assuming there are $144{,}000 \times 0.65$† or 93,600 B.t.u. in a gallon of oil fuel (page 22) used in an oil burner in this residence, the saving in oil fuel is

$$85{,}037{,}400 \div 93{,}600 = 908 \text{ gallons of oil fuel}$$

Because of a fuel saving of 41.8 per cent in this residence a correspondingly smaller amount of radiator surface will be needed for heating the house. The radiation required as calculated by the usual methods (page 292) was 625.‡ Allowing a reduction of 41.8 per cent in heat loss and consequently also in the amount of radiator surface needed, the square feet of radiation in the house when the walls and the roof have been insulated with rock wool is $625 \times (100 - 41.8) = 364$. If the insulation is put into

* Hours for heating this residence (October 1 to May 1) are 210 days × 17 hours, or 3,570 hours.

† Assume heating efficiency of 65 per cent.

‡ The total heat loss per hour for the entire house when calculating total radiator surfaces on the base temperature of 15°F. above the lowest recorded temperature in the locality. In this case the base minimum temperature is $-26 + 15$ or -9°F. (page 302), and the total heat loss on this basis is $57{,}020 \times \frac{70 - (-9)}{70 - 40}$ or $57{,}020 \times \quad = 150{,}180$ B.t.u. per hour. Corresponding square feet of radiation with steam at 215°F. is $150{,}180 \div 240$ (p. 292), or approximately 625 square feet.

a new house, there will be a saving in the item of radiators amounting to the cost of 625 − 364 = 261 square feet. Assuming an average price of $125 per square foot of radiation, the cost of the house will be 261 × $1.25 or $326.25 less than it would be without the insulation in the walls and the roof.

Annual Charges for New House.—A fair estimate based on average costs for the complete installation of the best rock-wool insulation is about $650.00 so that in a *new* insulated house the *net cost* of insulation is reduced from $650 to $326.25 or $323.75*

Annual charges on net cost of insulation in new house:

1. Depreciation (based on 25-year service) is $323.75 × 1/25....	$12.95
2. Average annual interest (6 per cent)........................	9.71*
Total annual charge for net cost of insulation in new house.....	$22.66

* During the period of charging off net first cost (25 years), there will be an interest charge of $323.75 × 0.06 for the first year; of $323.75 × 0.06/2 at the end of 12½ years; of $323.75 × 0 at the end of 25 years. This average interest charge is, therefore,

$323.75 × 0.06/2, or $9.71.

Annual Charges for Insulation in Same House Already Built.—In a house with walls already constructed and the heating system installed there can be, as a rule, no saving from a redesign of the radiator surfaces. Annual charges would, therefore, be calculated on the total cost of the insulation.†

Annual charges on total cost of insulation:

1. Depreciation (25-year service) is $625.00 × 1/25...............	$25.00
2. Average annual interest (6 per cent)..........................	18.75
Total annual charge for total cost of insulation..................	$43.75

After deducting depreciation and interest, there is a net saving per year for *new house construction* which varies according to the price of the oil fuel from $31.82 to $68.14.

* No saving is included for a possible reduction in the size of the steam boiler that is to be used.

† When the heat insulation can be put into the walls and roof of a house during construction, conveniently sized blocks of the insulating material can be used. Insulation can be economically inserted in the walls and roof of a building already constructed only by blowing insulation through a pipe and nozzle. This light-weight flaky insulating material should for satisfactory results be guaranteed not to settle at least within 5 years. If such material settles, it may be a better conductor of heat than the original walls. A "curly" mineral-type of filling is probably the best.

TABLE XXXV-A.—COST OF OIL FUEL SAVED BY WALL AND ROOF INSULATION

Cost of oil per gallon.	6 cents	8 cents	10 cents
1. Annual saving in oil fuel cost (908 gallons per year).	$54.48	$72.64	$90.80
For New-house Construction			
2. Total annual charges.	22.66	22.66	22.66
3. Net annual saving *after all deductions* (item 1 − item 2)	$31.82	$49.98	$68.14
For Completed House with Heating System Installed			
2*a*. Total annual charges based on total cost of insulation	$43.75	.75	$43.75
3*a*. Net annual saving *after all deductions* (item 1 − item 2*a*)	$10.73	$28.89	$47.05

Similarly in houses in which the heating system is installed for heating conditions without insulation of walls and roof, there is a net saving which varies from $10.73 per year for 6-cent oil fuel to $47.05 for 10-cent oil fuel.

CHAPTER XI

FANS AND BLOWERS

Centrifugal Fans.—The so-called "gravity" circulation is commonly used for the distribution of warm air to the rooms of a building heated by the ordinary type of warm-air furnace. This kind of circulation is always uncertain in operation as the air distribution is affected by the direction of the wind outside the building. Such a wind effect will cause the discharge of the greater amount of warm air on the leeward side and the lesser amount on the windward side where, of course, the greatest amount of heat is needed. In order to overcome the difficulty of such uneven gravity heat distribution, centrifugal ventilating fans are used with good effect, as the heat distribution that is obtained by means of the fan is positive and is therefore not influenced by the direction of the wind. Fans used for air circulation are of two kinds: (1) disk or propeller type, and (2) centrifugal type. *Disk* or propeller fans have usually a small number of nearly flat blades set at a uniform angle to the plane of rotation. Such fans are best illustrated by the electric disk fans commonly used in offices, shops, and dwellings. Fans of this type are usually of very light construction with the vanes arranged as in a screw propeller for a ship. *Centrifugal* fans are used almost exclusively for large-volume air distribution in pipes and ducts. Such a fan consists essentially of a number of blades either flat or curved, attached to radial arms springing from a central hub through which the driving shaft passes, as in the "spider" type shown in Fig. 208; or the blades may be attached to a conical plate as in Fig. 209.

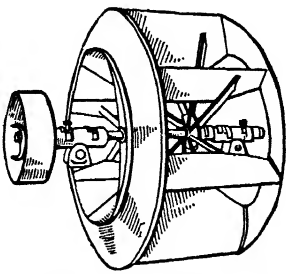


Fig. 208.—Spider-type ventilating fan.

Multiblade centrifugal fans which are the ones nearly always used in residences where there is forced warm-air distribution

through pipes and ducts, are usually of the "squirrel-cage" type, as shown in Fig. 210. Fans of this type can be designed to give very high efficiency because of two characteristic features in their designs. By the use of very short blades, a large space for

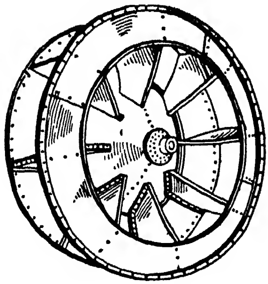


FIG. 209.—Conical-plate type of centrifugal fan.

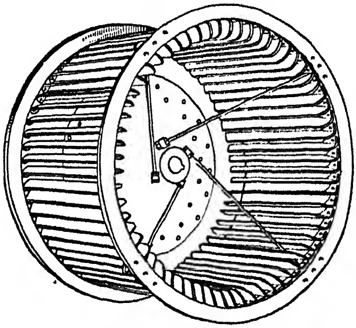


FIG. 210.—Squirrel-cage type of centrifugal fan.

the air intake is provided; and this space, being practically unobstructed, gives a very free suction. The other important feature of this fan is that the air leaves the blades at a higher velocity than that at which the tips of the blades are moving. Simple velocity diagrams, constructed like parallelograms of forces, and shown in Figs. 211 and 212, illustrate this point very clearly. In the case

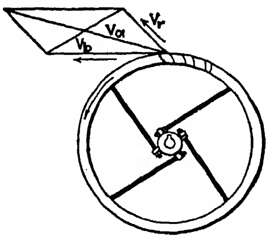


FIG. 211.—Graphic representation of velocities in multiblade centrifugal fan.

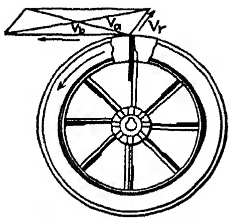


FIG. 212.—Graphic representation of velocities in straight-blade centrifugal fan.

of the multiblade fan, as illustrated in Fig. 211 by a velocity diagram, the velocity of the tips of the blades V_b, the velocity of relative flow of air in the blades V_r, and the absolute velocity of the discharged air V_a are shown in appropriate velocity proportions in the diagram. It will be observed that in Fig. 211 the

discharge velocity of the air V_a is nearly 50 per cent greater than the velocity of the tips of the blades V_b. On the other hand, a similar velocity diagram or parallelogram of forces is shown in Fig. 212 for a fan that has straight radial blades. In this case, the absolute velocity of the discharged air V_a is actually considerably less than the velocity of the tips of the blades V_r.

Centrifugal fans are usually attached to an extension of the shaft of the prime mover that drives them. In large buildings, the prime mover may be an electric motor, a steam turbine, or a steam engine, but in residences it is practically always an electric motor (page 287). Air enters at the center of the fan wheel

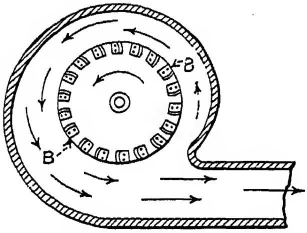


FIG. 213.—Typical spiral casing of centrifugal fan with short blades.

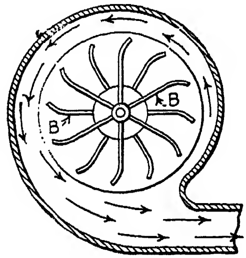


FIG. 214.—Spiral casing of centrifugal fan with long blades.

and is discharged from the tips of the blades by centrifugal force into a spiral casing which surrounds the fan as shown in Figs. 213 and 214. The shape of the blades and of the spiral casing is important if the fan is to be efficient and quiet.* It is a characteristic of centrifugal fans that the volume of air delivered can be regulated by varying the size of the opening at the inlet or suction side of the fan. Centrifugal fans may be classified in the following three groups: (1) forwardly curved blade fans, in which the tips of the blades curve forward or in the direction of rotation; (2) backwardly curved blade fans in which the blade tips curve toward the rear; and (3) radial blade fans, the vanes of which point radially like the spokes of a wheel.

Forwardly curved fans have the advantage of cheapness, light weight, and small space requirement. Offsetting these advan-

* Quiet operation will depend, however, more on relatively low discharge-air velocity than on design shapes of the fan.

tages are the disadvantage that they are in most cases* the least efficient of the three types enumerated and are unstable in operation, when, for example, one fan of this kind is used in parallel operation with another fan, on account of the tendency of one of

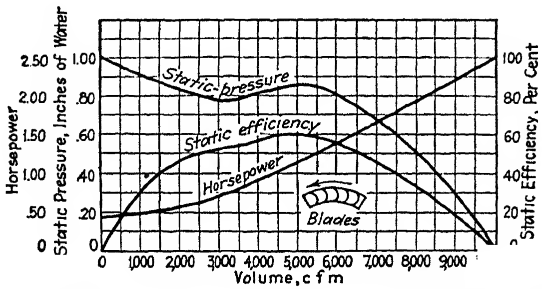


FIG. 215.—Horsepower and efficiency curves of centrifugal fan with forward-curved blades.

the two fans thus operated to take an unequal share of the air volume to be distributed, and thus overload the motor driving the fan taking the extra volume of air. The forwardly curved type of fan is in some cases limited to slower speeds of operation than the other types and for electric direct-connected drives, slow-

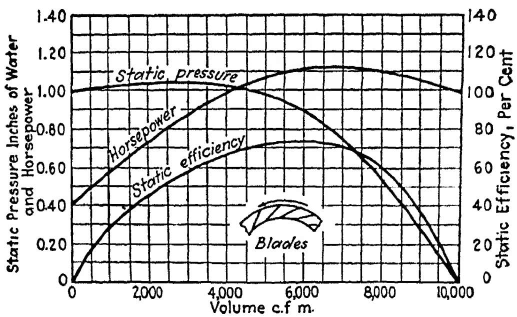


FIG. 216.—Horsepower and efficiency curves of centrifugal fan with tangential backward blades.

speed operation requires larger and more expensive electric motors than for high-speed operation.

Backwardly curved fans, although more expensive than the forwardly curved fans, have the advantage of being especially suited

* There are, however, important exceptions when the fan of this type fits exceptionally well the motor speed.

to high operating speeds and to operation by relatively small direct-connected electric motors. This type is a high-efficiency fan operating commonly at from 65 to 70 per cent.

A so-called "turbine" fan has found extensive application largely because of its very high efficiency, small size, and high

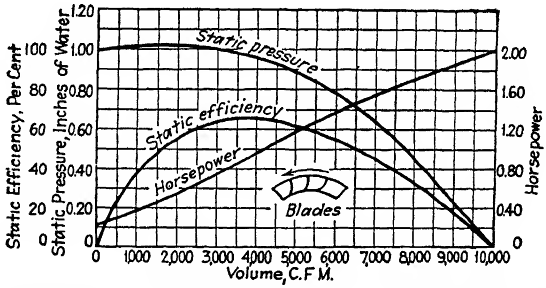


FIG. 217.—Horsepower and efficiency curves of centrifugal fan with turbine-shaped blades.

operating speed. It may be called a compromise design between the fans with forwardly curved blades and those with backwardly curved blades.

Horsepower required to drive the various types, including the turbine fan and also their efficiences, is shown in Figs. 215, 216,

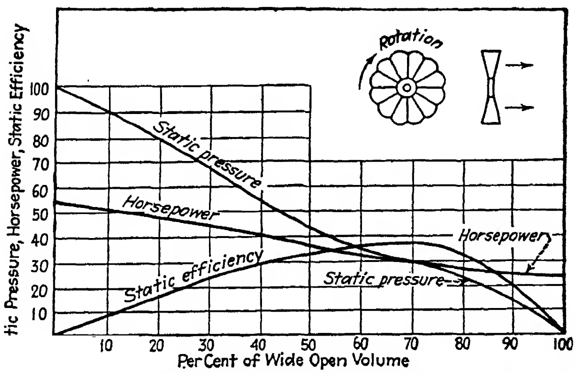


FIG. 218.—Horsepower and efficiency curves of disk or propeller fan.

217, and 218. It will be noticed that the efficiency curves of the four kinds of fans do not differ a great deal in shape but show very large variation in the percentage of maximum efficiency. The efficiency of the backwardly curved fan is higher than that of any

of the others. The efficiency of the disk or propeller fan, it will be noted, is very much lower than that of any of the others.

Horsepower curves for the forwardly curved fan and for the turbine-blade fan have somewhat similar characteristics as both are nearly "straight-line" curves. Such curves that represent increasing values of horsepower as the load is made larger are an undesirable feature for the reason that an oversized motor* is required for the contingency that the pressure resistance in the fan-discharge system may decrease so as to put on the fan an unusually large load from the increased quantity of air that will have to be handled. On the other hand, the horsepower curves for the backwardly curved fan and the disk or propeller fan attain a maximum value; then, when the pressure resistance continues to be reduced, a smaller and smaller amount of power is needed for the operation of the fan.

Fan Speeds for Alternating-current Motors.—In determining the speed at which a fan is to operate, the fan speeds given in Table XXXVI may be used when direct-connected induction motors are used.

TABLE XXXVI.—FAN SPEEDS FOR ALTERNATING-CURRENT MOTORS

Cycles	Revolutions per minute							
60	425	490	570	680	860	1,150	1,740	3,400
50	360	410	475	570	715	965	1,450	2,800
25	180	205	240	275	360	480	725	1,400

Fan Equations.—When applying the following fan equations to changing volume, pressure, and horsepower conditions, it is well to remember that for all practical purposes in the range used, a fan, whether disk or centrifugal, may be considered a constant-displacement medium; that is, against any given air resistance, for every revolution made, the fan moves the same quantity of air. Important fan equations are given below, being intended, of course, for the same fan when operating against the same air resistance with assumed constant efficiency.

If V_1, SP_1, and HP_1 represent cubic feet of air per minute, static pressure (page 284) in inches of water column, and horse-

* This condition is practically never present in the use of such fans for ventilating work.

power at known conditions, and if V_2, SP_2, and HP_2 are these quantities at the desired conditions, then for centrifugal fans of different sizes but of exactly the same proportions, if D is the diameter of the fan wheel in inches, the following equations may be stated:

$$\frac{V_2}{V_1} = \frac{\text{r.p.m.}_2}{\text{r.p.m.}_1} \tag{35}$$

$$\frac{SP_2}{SP_1} = \left(\frac{\text{r.p.m.}_2}{\text{r.p.m.}_1}\right)^2 \tag{36}$$

$$\frac{HP_2}{HP_1} = \left(\frac{\text{r.p.m.}_2}{\text{r.p.m.}_1}\right)^3 \tag{37}$$

$$\frac{V_2}{V_1} = \left(\frac{D_2}{D_1}\right)^3 \tag{38}$$

$$\frac{SP_2}{SP_1} = \left(\frac{D_2}{D_1}\right)^2 \tag{39}$$

$$\frac{HP_2}{HP_1} = \left(\frac{D_2}{D_1}\right)^5 \tag{40}$$

Example 1.—A centrifugal fan operating at 1,160 revolutions per minute delivers a volume of 3,000 cubic feet per minute of air against a pressure resistance of 0.5 inch of water column and requires 0.362 horsepower. The speed of the fan is then raised to 1,750 revolutions per minute. What will then be the volume of air discharged in cubic feet per minute, static pressure and horsepower?

Substituting in equation (35),

$$\frac{V_2}{3{,}000} : \left(\frac{1{,}750}{1{,}160}\right)^3$$

$$= \frac{3{,}000}{1{,}1} \quad : 4{,}526 \text{ cu. ft. per minute}$$

Using equation (36),

$$\frac{SP_2}{0.5} = \left(\frac{1{,}750}{1{,}160}\right)^2$$

$$SP_2 = 1.14 \text{ inch}$$

Using equation (37),

$$\frac{HP_2}{0.362} \quad \left(\frac{1{,}750}{1{,}160}\right)^3$$

$$HP_2 \quad 1{,}235 \text{ horsepower}$$

Example 2.—A 12-inch centrifugal ventilating fan delivers 1,600 cubic feet per minute of air against an airway resistance of 0.35 inch of water. It requires for its operation 0.15 horsepower. With the revolutions the same, if the diameter is increased to 18 inches and all other dimensions increased

in the same proportion, what will be the cubic feet of air discharged per minute, static pressure, and horsepower?

Substituting in equation (38),

$$\frac{V_2}{1{,}600} = \left(\frac{18}{12}\right)^3$$
$$V_2 = 5{,}400 \text{ cubic feet}$$

From equation (39),

$$\frac{SP_2}{0.35} = \left(\frac{18}{12}\right)^2$$
$$SP_2 = 0.788 \text{ inch}$$

From equation (40),

$$\frac{HP_2}{0.15} = \left(\frac{18}{12}\right)^5$$
$$HP_2 = 1.14 \text{ horsepower}$$

Centrifugal Fans, Air Compressors, and Blowers.—When centrifugal fans, air compressors, and blowers are used for supplying

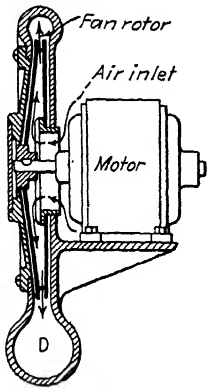


FIG. 219.—High-pressure centrifugal fan with disk rotor.

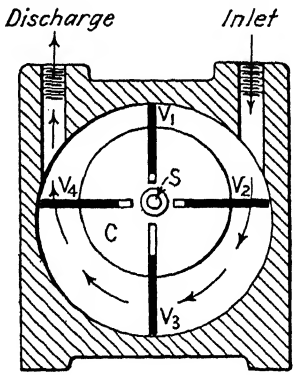


FIG. 220.—The movable-blade type of positive-pressure blower.

air under pressure for combustion in the domestic types of oil burners, they are usually operated by direct connection to an electric motor.

Another type of centrifugal fan suitable for somewhat higher pressures than those shown in the preceding figures is illustrated in Fig. 219. This type of centrifugal fan is also sometimes called a *centrifugal blower*. This latter type is especially suited for operation with the industrial types of burners, as the pressure possibilities are quite adequate for practically any of these burners,

including the air registers (page 297) for marine and industrial services. The blowers shown in Figs. 220 and 221, are well suited to supply air for combustion for such services. When, however, much larger volumes of air at much higher pressure are required, than are the limits of volume and pressure for this type of fan (1 to 8 ounces per square inch gage pressure), multistage centrifugal fans of this type are used. For such multistage service, several centrifugal fans are mounted on the same shaft. The several fans are connected in this arrangement so that the discharge pipe of the fan taking in atmospheric air is connected to the intake or suction side of the fan discharging air at the next higher pressure. Similarly, the air discharge from the second fan is conducted to the intake or suction side of a third fan where the pressure is still further increased. The discharge from the third fan may be similarly taken to the intake or suction side of a fourth fan, etc. Such a pressure pump is called a multistage centrifugal fan or blower, the discharge pressure increasing, of course, in each of the successive *stages* of a fan or blower.

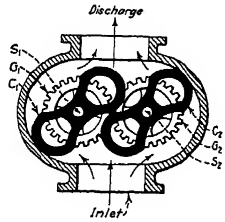


FIG. 221.—Roots blower.

Radial-vane and Roots Blowers.—The vane type of positive-pressure blower shown in Fig. 220 is much used for services requiring gage pressures from 1 to 5 pounds per square inch. The inlet and outlet connections of the blower are shown in the figure, and the direction of air flow is indicated by arrows. The blower is usually operated by an electric motor directly connected to the shaft S. There are four vanes, v_1, v_2, v_3, and v_4, which are located in radial slots in the cylinder C. The movement of the cylinder and of the radial vanes is, of course, in the same direction as the air flow. The air entering the compressor at the inlet is moved in a clockwise direction in the enclosure made by the shell of the blower, its end covers, and two of the consecutive vanes. Because of the shape of the chamber to

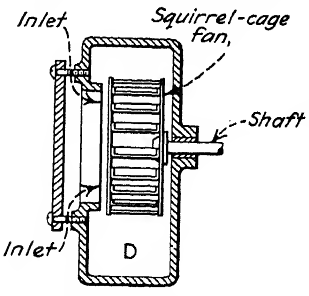


FIG. 222.—Low-pressure centrifugal fan.

which air is admitted at atmospheric pressure, it will be plain that when the radial vanes v_1 and v_2 get into the position shown by the vanes v_3 and v_4, compression of the air will begin, and discharge of compressed air occurs when the radial vane v_4 uncovers the exhaust port or outlet of the blower.

Another type of positive-pressure blower usually called "Roots blower" is shown in Fig. 221. In this blower, the suction or intake is at the bottom, and the discharge is at the top. The gear wheels shown in the figure are needed to transfer motion from the driving shaft S_1 to the driven shaft S_2, as usually the driving shaft S_1 is directly connected to an electric motor or similar source of power. The movements of the cam-shaped lobes C_1 and C_2 are not by any means simple, so that the operation of this type of blower cannot very well be explained without the help of a model.

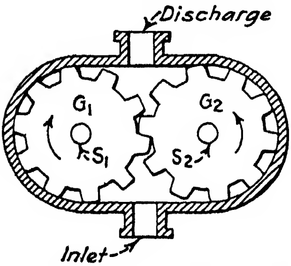


FIG. 223.—Gear type of pump.

The vane type (Fig. 220) does not operate satisfactorily at speeds much higher than 300 revolutions per minute, the speed limitation being due to the slowness of the in-and-out movement of the radial vanes. The Roots blower is suitable for much higher speed; and, in fact, it may be recommended for a total range of 100 to 1,800 revolutions per minute. These positive-pressure blowers develop sufficiently high pressures, especially if there should be obstructions in the discharge pipe, so that pressure relief valves are needed. A typical low-pressure centrifugal fan is shown in Fig. 222.

A conventional type of compressor* which has a reciprocating piston is ordinarily used when the gage pressure to be supplied is more than 5 pounds per square inch.

The piston type of air compressor is also often built in several stages, so that the compressed air from one cylinder is discharged into a second cylinder, which is made somewhat smaller in cubical contents, thus making a *two-stage* air compressor. If the air discharge from a two-stage air compressor is further compressed in a

* Modern reciprocating compressors are described fully in "Refrigeration," by Moyer and Fittz, 2d ed., pp. 109 to 134, 1932.

third cylinder with still smaller cubical contents, the combination of the three compressor cylinders makes a *three-stage*, piston-type air compressor.

Capacity and Leakage of Air Pumps and Blowers.—For a pressure type of atomizing-oil burner (page 94) a rotary-type pump (page 340) or a blower is generally found most satisfactory for supplying the required amount of air for combustion at the desired pressure. The rated capacity in air flow of such a pump or blower should always be considerably larger than the actual requirements, for the reason that the capacity is determined when the pump or blower is new; it is the general experience that after several years of service such a pump or blower will have a much lower capacity than it had when new, because of the leakage that inevitably develops between the cam lobes in the type like Fig. 221 or at the ends of the cylindrical rotor of the type shown in Fig. 224. Because of this leakage, it is customary to select a pump or blower that has (when new) a capacity several times as large as the actual requirements of the pressure type of oil burner that it is to supply with combustion air.

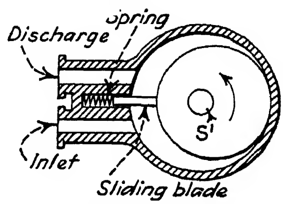


FIG. 224.—Cylindrical-rotor type of blower.

Pressure-relief Valves.—In practically all types of air-pressure equipment, except those intended only for compressed-air storage, it is necessary to provide a *pressure-relief valve* which will open when the maximum safe pressure in the device is reached. The maximum pressure, however, that is obtainable, in the centrifugal fans and blowers of the types just described, is not large enough to be dangerous.

Fan Noise.—One of the most important requirements in the selection of a centrifugal fan, compressor, or blower is a minimum of noise. It is a fairly general rule that for noiseless combustion a slow-speed centrifugal fan of rather large diameter will give the best results. A small low-pressure type of centrifugal fan, which is a design especially suited for domestic oil burners, is shown in Fig. 222. Noises from a centrifugal fan are usually traceable to excessive blade-tip speed or to a fan of insufficient capacity. A blade-tip speed which is excessive for a forwardly curved fan blade may not be excessive for a backwardly curved blade.

In any heating installation where a ventilating fan is installed to obtain positive circulation of the warm air, precautions should be taken that the noise produced by the operation of the fan and the electric motor that is ordinarily used to drive it is not carried through the various warm-air pipes and ducts to the rooms that are heated. The method commonly used to avoid such transmission of noise is to set the fan and its motor, which in small installations is practically always direct-connected, on thick corkboard or some other similar sound-absorbing and durable material, and also by so placing the fan with its motor that it will be as much as possible out of metallic contact with the ducts supplying the warm air to the various rooms. Flexible-cloth connections may be inserted between the fan outlet and the main warm-air duct.

In recent years, great advances have been made in the design of ventilating fans so that fans are now made that make considerably less noise than the best designs that were available only a few years ago.

When a suitably designed fan is used as an auxiliary in a gravity-air-distribution system, the warm-air furnace need not necessarily be in the center of the basement or cellar of a house, and the warm-air pipes and ducts need not be given so much slope as is necessary in an ordinary simple gravity-distribution system. The auxiliary use of the fan in connection with a hot-air furnace makes it possible to use to very good advantage rectangular rather than round ducts in all parts of a building and to place these ducts up against the ceiling of the basement or cellar so as to obtain headroom that will make the basement rooms much more usable than they would otherwise be.

Oil-supply Regulation.—The rate at which the oil fuel is delivered to a pressure type of oil burner is, of course, regulated by the size of its oil-supply nozzle and the pressure at which the oil enters the throat, or smallest cross section, of this nozzle. Excess supply of oil beyond requirements may be by-passed to the oil-storage tank or back into the suction piping of the oil pump.

Oil Pressure for Atomization.—For oil burners in which atomization is obtained by the discharge through a nozzle of oil fuel under pressure, the amount of pressure obtainable by an ordinary centrifugal type of ventilating fan is entirely inadequate. Consequently some kind of rotary pump is ordinarily needed to force

the oil fuel into and through the nozzle at a gage pressure usually between 80 and 125 pounds per square inch. A *rotary-gear pump* somewhat like the one shown in Fig. 223 is suitable for this purpose and is used in connection with many oil burners of the pressure-feed type. In essential parts, this rotary pump consists of a pair of gear wheels set together in an oiltight casing. One of the gears in such a combination is driven usually by an electric motor direct-connected to its shaft by means of a flexible coupling. Oil from the supply tank enters this rotary pump through the suction connection at the bottom and is discharged at the required pressure through the discharge connection at the top. In the operation of this pump, the oil fuel is "trapped" in the spaces between the gear teeth and the casing. Then, by the revolution of the gear wheels, it is carried around through approximately a half circle to the discharge opening. Leakage of the oil back through the center of the pump is prevented by the intermeshing of the teeth of one gear wheel with those in the other.

Obviously it is necessary that a pump for the operation of an automatic oil burner should be self-priming or, in other words, should be automatically primed. If the priming of the pump is not automatic, the pump and the piping must be filled with oil when the installation of the oil burner is made or when repairs are made requiring the removal of the pump or any of the attached piping. A *foot valve* is needed at the end of the suction pipe in order to prevent priming oil from draining away into the fuel-oil-supply tank during the intermittent periods when the oil burner is not in use.

CHAPTER XII

DRAFT AND CHIMNEYS

Conditions Affecting Draft of Oil Burners.—The movement of the air through the firepot of an oil burner, into the combustion chamber and out through the flue and chimney, is called *draft.* This movement of the air through a warm-air furnace or through a boiler is due (if no centrifugal fan or blower is used for supplying air) to the difference between the weight of a vertical column of unit area of hot combustion gases at the average of the temperatures in the furnace or boiler, the flue and the chimney and the weight of a vertical column also of unit area of cold outside air of the same height. The *intensity of draft* in an oil-burning furnace or boiler, as thus defined, depends on the *average* difference in pressure* between that of the hot combustion gases in the furnace or boiler, and the pressure of the outside air. The measurement of draft is explained on page 349.

The intensity of draft must be sufficient to move the combustion gases together with the excess air (page 27) through the firepot, the combustion chamber, the flue, and finally through the chimney. This movement of the gases and the excess or dilution air in an oil-burning furnace or boiler must be made against the following resistances: (1) Resistance to gas flow through the burner and combustion chamber; (2) resistance of the flue; (3) resistance of the damper in the flue; (4) the resistance of the chimney.

The first three of these items are more or less fixed in amount, and depend largely on the design of the boiler. The last item depends on the height, shape of cross section, and care in construction of the chimney. If, for example, the cross-sectional area of the chimney is too small, the frictional resistance to the flow of the hot combustion gases and the dilution air may be so large that

* This difference between gas pressure and air pressure is due to the combined influence of temperature difference between inside and outside air, the height of the chimney, and other factors such as chimney resistance.

the force of the draft is very small. On the other hand, if the area of the chimney is made considerably larger with the object of making its frictional resistance small, the force of the draft will be correspondingly larger.

Chimney Dimensions.—The size of a chimney required for an oil-burning heat installation can be worked out with more or less approximation by arithmetical calculations.* The accuracy, however, that can be expected from such calculations scarcely warrants the time required for it, so that as a rule, the chimney size is determined by reference to data as given in Table XXXVII. This table is an abridged statement of a more inclusive table that has been published by the American Society of Heating and Ventilating Engineers.

In the table, minimum chimney sizes are given for values of *steam*-boiler capacity in square feet of radiation. For a given size of chimney about 60 per cent should be added to the steam-radiation surface to get the number of square feet of *hot-water* radiation for which the chimney will be adequate. In other words, if the steam-boiler capacity in square feet of radiation is 2,000 and a rectangular chimney with an inside area of 250 square inches has been selected, this same size of chimney would be adequate for 2,000 times 1.60 or 3,200 square feet of hot-water radiation. For small sizes of chimneys, the data given in the table can be used also for determining the size of a warm-air furnace for which a chimney is adequate, the warm-air capacity of the furnace being expressed in square inches of leader pipe (page 291). For such determinations of the size of chimney for a warm-air furnace, the total area of leader pipe† carrying warm air from the furnace is approximately ⅓ larger than the number of square feet of radiation supplied by a steam boiler for a given size of chimney. Thus, according to the table, a round chimney with an inside area of 79 square inches is the minimum size for a steam boiler to take care of 690 square feet of radiation. The total area in square inches of leader pipe of a warm-air furnace for which this chimney will be adequate would be then according to

* A.S.H. and V.E. "Guide," p. 357, 1936.

† Unless headroom is an important consideration, leaders are usually made of round pipe, and should be given a pitch of at least 1 inch per foot of length. All the leaders should leave a warm-air furnace at the same height above the floor.

this rule 690 × 4/3, or 920 square inches. This rule gives sufficiently good approximations at least for checking the adequacy of chimney areas for warm-air furnaces.

TABLE XXXVII.—MINIMUM CHIMNEY SIZES FOR STEAM-HEATING BOILERS

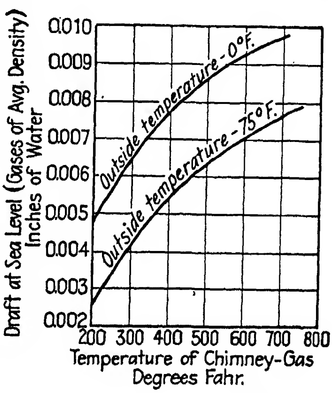
Steam-boiler capacity, square feet of radiation	Rectangular chimney		Round chimney		Chimney height, feet above burner
	Inside dimensions of fire-clay lining, inches	Inside area, square inches	Inside diameter of lining, inches	Inside area, square inches	
590	7 × 11½	81	..	...	35
690	....	...	10	79	
900	11¼ × 11¼	127			
900	6¾ × 16¼	110			
1,100	....	...	12	113	40
1,700	11¼ × 16¼	183			
1,940	....	...	15	177	
2,480	17¼ × 17¼	298	..	...	45
3,150	....	...	18	254	50
5,000	21 × 21	441	..	...	55
6,980	....	...	24	452	65
8,700	28 × 28*	784			
9,380	....	...	27	573	
10,470	28 × 32*	896			

* Dimensions are for unlined rectangular flues.

Total Available Draft of Chimney.—When chimneys are properly designed and constructed, so that the draft losses (page 346) are minimum amounts, the total draft of a chimney can be calculated from the curves given in Fig. 225. In this figure, two curves are given, one for an outside temperature of 0°F. and the other for an outside temperature of 75°F. The abscissas for these curves are average chimney-gas temperatures, ranging from 200° to 700°F. Maximum chimney temperatures given by these curves are very much higher than those that are ordinarily used for the calculation of draft for boilers or warm-air furnaces, using a solid fuel.*

* For the design of small chimneys, the temperature of chimney gases for boilers and warm-air furnaces using solid fuel is usually within the relatively narrow limits of 200° to 300°F. (Harold L. Alt, Chimneys, Their Design and Construction, *Heating and Ventilating Magazine*, March, 1917).

A comparison of values in the table shows that a round chimney is more efficient per square foot of area for draft production than one that is rectangular. Nevertheless, the rectangular chimney is nearly always used for small buildings because, if made of brick or stone, the construction cost is very much less than that of a round chimney. A good chimney, whether rectangular or round, should be lined with tile and should be smooth and free from air leaks. An offset in a chimney obviously increases the resistance to the natural flow of the chimney gases and should therefore be avoided; and if the chimney must be constructed with an offset, the change of direction of the axis of the chimney because of the offset should be made as gradual as possible.



relation imney g temperature for small residence chimneys (per foot of height).

Effect of Wind on Draft.—When a chimney is not built high enough to carry it above the roofs of surrounding buildings, there is always the possibility that wind will be deflected by these buildings, so that it will blow down into the chimney, and thus very much reduce or possibly even neutralize the draft.

Draft Measurement.—The unit of measurement of draft is usually the *inch of water*, although draft may also be expressed in terms of pressure of ounces or pounds per square inch.*

The usual procedure in measuring difference in pressure due to draft is to connect a U-tube partly filled with water to the flue or chimney in which the draft is to be measured. In Fig. 226 such a U-tube is shown with the water levels in the two "legs" at the same elevation. There is a short scale for length measurements between the two legs of the U-tube. If a hole is made in the smoke pipe or chimney of a boiler and a small pipe is inserted through it, a draft gage may be suitably connected. The level

* Pressure differences in inches of water can be converted to pounds per square inch by multiplying the inches of water by 0.036, or conversely pounds per square inch may be converted to pressure difference in inches of water by multiplying the pounds per square inch by 27.78.

of the water in the leg of the U-tube connected to the pipe entering the flue will be raised above that in the other leg because of the lower pressure in the flue or because of the *draft*. In other words, the water level is elevated in the leg connected to the flue, for the reason that the pressure acting on the surface of the water in that leg is less than the atmospheric pressure acting on the other (open) leg of the U-tube. The difference in height between the water columns in the two legs is a measure of the difference in pressure (of course in inches of water) on the water surfaces in the two legs.

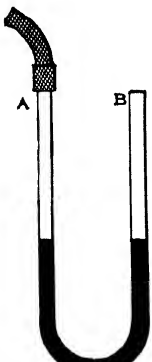


FIG. 226.—U-tube draft gage.

A scale graduated in inches and fractions of an inch is ordinarily provided as shown in Fig. 226 so that the difference in elevation of the surfaces of water in the two legs of the U-tube can be readily measured in inches if the graduations of the scale are in inches and fractions of an inch as they usually are in countries where the English system of units is commonly used.

For fairly accurate work, the bore of the U-tube should not be less than about ⅛ inch; obviously, the length of the tube connecting the U-tube with the flue or breaching of a boiler or with a chimney should not be longer than is really necessary. There is always the danger that if a rubber tube is connected to the glass U-tube and the other end of the tube is inserted into a flue, the tube will be nearly closed at the point where it passes through the metal of the flue; and, in that case, the draft measurements would be inaccurate. For this reason, the best arrangement in setting up a draft gage is to insert a short brass or iron tube (preferably ⅛ inch iron-pipe size) into a hole of about the proper size made into the flue or the chimney, and attach the rubber tube at one end to the "outside" end of the metal tube, and at the other, to one of the legs of the draft gage, whether it is of the U-tube type or of some other.

Inclined-tube Draft Gage.—The kind of draft gage shown in Fig. 226, which is set up with its two legs in a vertical position, is not adaptable to very accurate reading of the graduated scale. In order to make possible more accurate determinations of draft than can be obtained with the ordinary U-tube, an inclined type of draft gage has been devised. A typical inclined-tube draft

gage is shown in Fig. 227. This inclined type of draft gage is connected up to the flue, breeching, or chimney, by rubber tubing attached at *A*. The other end of the tube *B* is open to the air and is subjected, therefore, to the ordinary atmospheric pressure. On this scale, the distances between the units which measure equivalent inches of water are very much longer than the actual. Vertical distances, however, between the marks on the scale corresponding to the elevation of the inclined leg of the draft gage may be exact fractions of an inch in length, so that it is easy to see that in theory a draft gage of this type can be used to measure with accuracy changes in elevation of the water on the scale of the inclined gage in the usual fractions of an inch of water. Further, the readings on the graduated scale placed behind the inclined leg read "difference in elevation." When the leveling

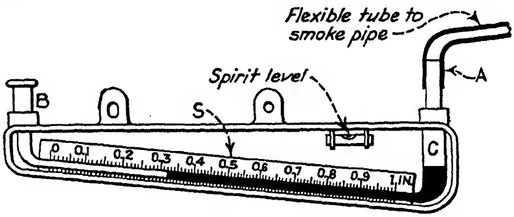


FIG. 227.—Inclined-tube draft gage.

device (spirit level) of the gage is adjusted so that its "bubble" is at the middle position, *vertical* differences in elevation of the liquid in the inclined tube may be observed on the scale *S*. The difference between the readings from the graduated scale will give directly the difference in pressure in inches of water just as with an ordinary U-tube. Unless the reservoir *C* at the right-hand side of the instrument is very large in diameter and consequently in volume in comparison with the volume of liquid in the inclined tube, it is best to mark the graduations on the scale *S* for every half inch by comparison with an ordinary U-tube. Intermediate dimensions usually in tenths of an inch, as shown in the figure, can then be marked with the help of a draftsman's divider.*

Precautions for Accuracy of Draft-gage Readings.—The opening that must be made in a duct, breeching, or chimney for the

* The theory of the inclined draft gage is explained in "Power Plant Testing," by James A. Moyer, 4th ed., McGraw-Hill Book Company, Inc., New York, 1934.

insertion of a metal tube to which the flexible (usually rubber) tubing connected to the draft gage is attached, must usually be made necessarily somewhat larger than the exact size of the metal tube. If there is opportunity for the admission of air in the space between the metal tube and the material in which the hole has been made for its insertion, the draft that is being measured will be unfavorably influenced, and the measured draft will not be the same as that which would have been obtained if there were not such an air leakage. On this account, the metal pipe to which the draft gage is attached should be well sealed into the

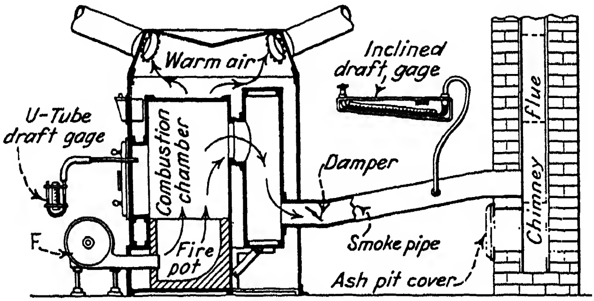


FIG. 228.—Draft gages as applied to draft measurement in warm-air furnace.

material through which it enters the duct, breeching or chimney. For temporary use of the draft gage, a stiff mixture of plaster of paris and water, or putty, may be applied around the tube.

Test for Air Infiltration.—If a draft gage is connected into the smoke pipe of a warm-air heater or a boiler as indicated in Fig. 228 and the readings of the draft gage are taken, first when all the doors and other openings of the warm-air heater or boiler are closed as they are for the normal operation and again when all possible leakage places have been closed, the difference between the readings of the draft gage will indicate the relative amount of air infiltration that enters through other places than those intended for the admission of air for combustion. The method of bringing a lighted candle near all possible places of leakage which will be observed when the tip of the candle flame is drawn by the draft in the chimney toward the casing of the heater or boiler is also a good test of inward leakage.

CHAPTER XIII

AIR-CONDITIONING TESTS

Meaning of Air Conditioning.—The occupants of a room are continually vitiating the air by reducing the amount of oxygen it contains and at the same time increasing the amount of carbon dioxide. Besides these changes in the air which are chemical, there are those caused by giving off from the mouth, skin, and clothing organic matter which is usually recognizable by its objectionable odors. Air in poorly ventilated rooms* becomes especially objectionable, however, when occupied by large numbers of people. This results from the increase in the temperature of the air from body heat and the increase in the moisture content of the air (humidity) caused by both visible and invisible perspiration that is constantly being discharged from the skin and also by respiration from the lungs of the occupants.

There is always the possibility that breathed air when inhaled by others may be the means for the distribution of disease germs. Infected particles of moisture from coughing and sneezing contaminate the air only in the immediate vicinity of the infected person, and not nearly all common colds are contagious. Nevertheless the mouth spray from coughing and sneezing is much like a coarse rain which settles down quickly. In this case the disease germs are carried such short distances that they produce only contact infection by distribution in the air. About all that can be stated with certainty in regard to the objectionable properties of breathed air is that it is odorous and offensive, mostly as the result of body heat, to the extent that it is capable of producing headache, nausea, and lack of appetite. These effects alone are sufficient to warrant the better conditions which may be obtained by satisfactory air conditioning. The fact, however,

* Outdoor air under normal conditions contains about 21 per cent by volume of oxygen. From air actually breathed, an adult removes 4 per cent of the oxygen. Since it is possible for a human being to live in an atmosphere containing only 12 per cent of oxygen, it is obvious that recirculation of air is not necessarily harmful.

that in breathed air there is an increase in humidity in a room because of the evaporation of moisture from the skin and lungs far in excess of the heat that is transmitted in hot weather through the windows and walls makes the problems of air conditioning by cooling much more difficult than that of heating the same space in winter. In either case—that is, in summer or winter—the indoor-air conditions in buildings that are properly air-conditioned must be such that the occupants will be comfortable during both seasons; and at the same time the sensations of chill and intense heat on entering and leaving will be avoided.

Humidity Required for Good Health.—It is generally understood that humidified, rather than dry air, is necessary for healthful indoor conditions. Even though a person may be relatively comfortable in a dry atmosphere, this condition is not the best for good health. Very dry air has, of course, a harmful effect on the mucous membranes of the respiratory organs and makes them *susceptible* to the inroads of disease-carrying germs. It is generally stated that for good health conditions, the amount of moisture in the air of living rooms and offices should not be much less than 40 per cent of the amount of moisture in fully saturated air.*

Table XXXVIII.—Weight of Water Vapor in Air

Temperatures, °F....	0	10	20	30	40	50	60	70
Grains per cubic foot.	0.5	0.8	1.2	1.9	2.9	4.1	5.8	8.1

It is a well-established fact that too low a moisture content is objectionable from a comfort and health standpoint. It must be noted, however, that air having too high a percentage of moisture is also objectionable, especially in warm weather, when everyone has experienced the discomfort due to moist, warm air. There is another entirely different kind of difficulty that results from too much moisture in the air in rooms during winter weather. This other difficulty is caused by the condensation of the moisture in the air upon the glass of windows and doors when the percentage of moisture in the air is large enough to produce condensation at the temperature of the window. Of

* For a table of the properties of completely saturated air and of dry air, see "Air Conditioning," by Moyer and Fittz, pp. 13 and 14, McGraw-Hill Book Company, Inc., New York, 1933.

course, when there is condensation on the glass of windows and doors, the percentage of moisture in the air that is *very close to the glass* is obviously about 100 per cent of what the air can carry. When air is saturated, the so-called *relative humidity* of that air is 100 per cent. Similarly when the moisture in the air is 40 per cent of the amount it carries when saturated, its relative humidity is 40 per cent.

Table XXXVIII gives the *approximate* weights* of vapor per cubic foot when saturated at various temperatures.

Relative Humidity.—Relative humidity may therefore be defined as the ratio of the weight of the moisture (steam) in a given space to the weight of moisture (steam) which the same space is capable of containing when fully saturated at the same temperature. Relative humidity is usually expressed as a percentage: For example, saturated air at 70°F. contains approximately 8 grains of moisture per cubic foot. Now, if another sample of air also at a temperature of 70°F. contains 4 grains of moisture per cubic foot, the relative humidity of the second sample is 4 ÷ 8 or 50 per cent.

Dew Point.—The saturation temperature of air is called the dew point, meaning, briefly, the temperature of air at which saturation is obtained for a given weight of water vapor, or, in other words, it is the temperature of air at which any reduction in temperature causes condensation of some of the contained moisture. Any weight of water vapor in air will correspond to some temperature at which that air will be saturated and at which any lowering of the temperature will cause condensation.

A proper relative humidity to be maintained in public buildings is from 35 to 50 per cent. The relative humidity usually recommended in good practice is 40 per cent, with a room temperature of about 68°F. This corresponds to about 3 grains of moisture per cubic foot of air and a dew point of 42°F. Even this amount of moisture will cause condensation on the windows of a building in extremely cold weather, so that a lower humidity should be maintained in very cold weather if condensation on the windows is objectionable.

Dry-bulb and Wet-bulb Thermometers.—Usually the temperature of the air is determined by means of an "ordinary" or dry-bulb thermometer. A wet-bulb thermometer has its bulb covered

* Weights are given in grains. One pound is equal to 7000 grains.

with a piece of clean, soft cloth which must be dipped in water before taking a reading. Care should always be taken to keep the cloth free from dirt and to use clean, pure water for wetting. This wet-bulb thermometer (Fig. 229), will give a depressed or lower reading compared with that of the dry-bulb thermometer in proportion to the amount of evaporation from the surface of the cloth on the wet-bulb thermometer; and this difference in the readings, or depression, is a measure of the amount of moisture in the air. This reading of the wet-bulb thermometer corresponds to the temperature at which the air would be normally saturated without any change in its heat contents. In order to obtain an accurate wet-bulb reading, it is necessary that the thermometer should be placed in a strong current of air. There is a small radiation error in the observation of the true wet-bulb reading by a stationary wet-bulb thermometer. This is negligible for practical engineering purposes when a vigorous whirling motion is maintained. For very low air velocities, as in natural currents of air, the wet-bulb thermometer will not drop to the true saturation, or wet-bulb, temperature of the air. In order to minimize the wet-bulb error to a point where it may be entirely neglected for ordinary engineering work, some form of sling or aspiration psychrometer should be used for wet-bulb-temperature observations in still air.

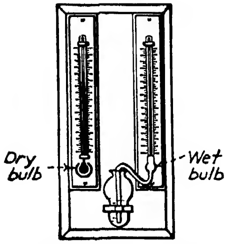


Fig. 229.—Wet- and dry-bulb thermometers.

Sling Psychrometers.—A wet and dry-bulb thermometer mounted on a strip of metal, as shown in Fig. 230, and provided with a handle which permits it to be rapidly whirled through the air, is called a sling psychrometer. When being used, the instrument should be whirled continuously until no further drop in the wet-bulb reading is noted. The difference between the readings of the two thermometers is the wet-bulb depression. There are other forms of instruments, generally of a stationary type, used for taking humidity readings, but the sling psychrometer is reasonably accurate and is the one used by the U. S. Weather Bureau. It may be difficult to get consistent results with a sling psychrometer unless the peripheral velocity of the wet bulb is not less than 15 feet per second. For an 8-inch sling psychrometer, this is about 3.5 revolutions per second.

Manually and Mechanically Operated Psychrometers.—A great deal of survey work in connection with air conditioning must be done in the rooms of buildings that are occupied by numerous employees as well as by customers, etc., so that diversion of attention is caused when a person operates the usual type of sling psychrometer. A professional engineer is sometimes embarrassed because of the publicity he gets from using such an instrument in public places. There is also the difficulty that the sling psychrometer is not adaptable at all to the determination of humidity close up to windows when investigating frosting conditions (page 359). There are several reasons, therefore, why a more compact kind of psychrometer than the sling type should be available.

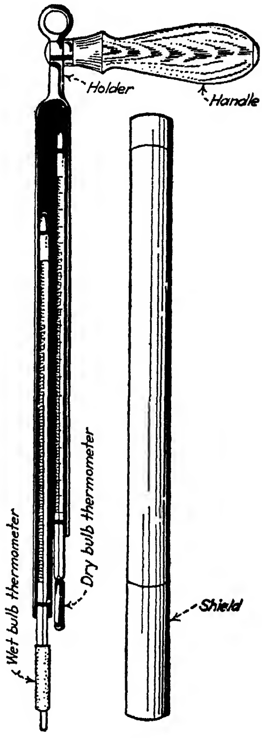


FIG. 230.—Sling psychrometer.

The manually operated aspirated psychrometer shown in Fig. 231 has been designed especially to avoid these difficulties. Accuracy is claimed for it equal to that of any first-class sling psychrometer, and in the hands of an unskilled operator it is likely to give much higher accuracy. This psychrometer consists of a pair of good-quality thermometers T_1 and T_2 such as are on sling psychrometers, but arranged so that the necessary aspiration over the bulbs is induced by a steady jet of air applied from a hand pump *B*, which is used to inflate the flexible reservoir *C*. This air reservoir is intended to even out the impulses of the hand pumping and provides a steady flow of air to a small nozzle which is located inside the *Venturi tube D*. The action of the jet of air coming from the flexible reservoir *C* induces as it passes through the Venturi tube a larger supply of air which is drawn in through slotted chambers, one of which is marked *E* in the figure. The chambers in which there are these slots surround the wet- and dry-bulb thermometers; thus these thermometers are provided

with an adequate air flow which is practically independent of the temperature of the air in the flexible reservoir *C* to give correct wet- and dry-bulb temperatures. The chamber receiving the outside air through the slot *E* has a cover on the top side which can be opened to apply water from the supply carried in the bottle that is provided. The wet-bulb wick can be thoroughly wetted when this cover is raised; but at the same time, care must be taken that there is no free water deposited around the bulb which might get near the dry bulb. The handle of the instrument also forms its case, and when not in use, the thermometers and the mechanism of the psychrometer slide into the handle *H*

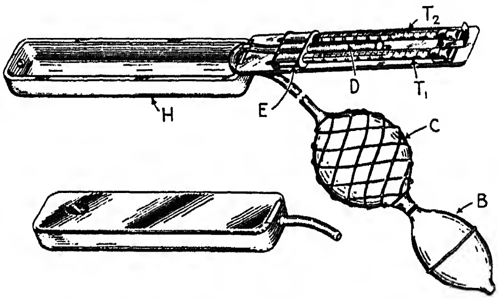


FIG. 231.—Aspirated psychrometer with hand-operated pump.

to make a very compact pocket instrument. The folded instrument is shown at the bottom of the figure.

A kind of psychrometer has been designed by Assmann in which the dry- and wet-bulb thermometers are enclosed in a metal casing, and a small fan operated by a spring motor similar to that used on portable phonographs is used to circulate air through the casing. The air intakes are at the bottom and the outlets are near the top. The fan produces a rapid and uniformly constant circulation of air over the two thermometers. The obvious advantage of this device over the commonly used sling psychrometer is that thermometers are protected from radiation and there is at all times uniformly rapid circulation of air and wet-bulb evaporation through the instrument. A typical aspiration psychrometer of this kind is shown in Fig. 232.

The hand-operated psychrometer in Fig. 231 is especially useful for checking the operation of a windowstat, as shown in Fig. 233.*

* Made by Julien P. Friez and Sons, Inc., Baltimore, Md.

One of the difficulties, as often observed in the operation of air-conditioning apparatus in small buildings and especially in residences, is that humidity is not controlled sufficiently to avoid *frosting of windows*. In fact, the major problem of winter air conditioning has been the excessive condensation that takes place on windows, badly insulated walls, or other cold surfaces during winter weather, where otherwise helpful humidities are maintained artificially by means of a humidifier and other winter air-conditioning equipment. One method of avoiding this difficulty of condensation, especially on windows, is to use especially constructed window sashes consisting of two or more panes of glass in a single steel casing with a narrow dehydrated air space between any two panes. This use of multiple thicknesses of glass is one way to prevent window-frosting due to poorly regulated humidification of the air in rooms.*

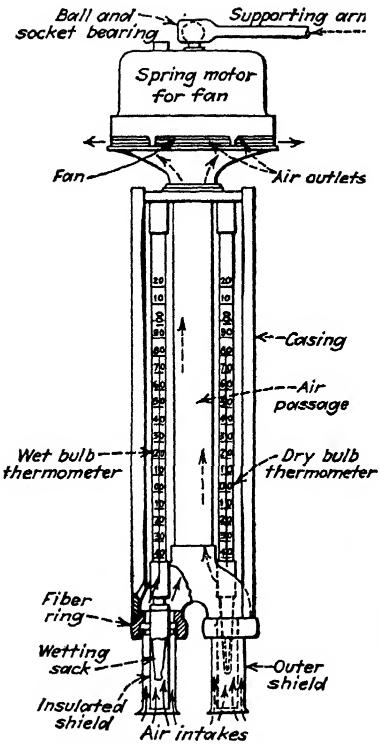
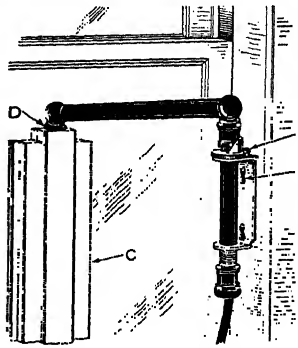


FIG. 232.—Motor-operated aspirated psychrometer.



233.—Window humidistat to prevent frosting.

The *windowstat* is easily adapted as an additional control instrument in any system of humidification. This instrument

* Double-glass window sashes are made by Pittsburgh Plate Glass Company, Pittsburgh, Pa.

consists of a humidistat C (Fig. 233) which is supported by a bracket hung on pins, one of which is marked E. Care should be taken that the windowstat is fastened firmly and in such a manner that it will hinge forward to bear definitely on the pane of glass on which it is intended to operate; yet it should be hinged so that it can be turned back and away from the window when it is to be opened.

The operating part of the windowstat is in the casing C. It is a simplified humidistat which operates electrically to stop humidifying devices at the setting of the enclosed humidistat corresponding to about 98 per cent relative humidity which is approximately the point at which frosting at a window would begin. This means, of course, that the relative humidity close to a window pane is entirely different from what it is in the room in which the room-controlling apparatus is located.

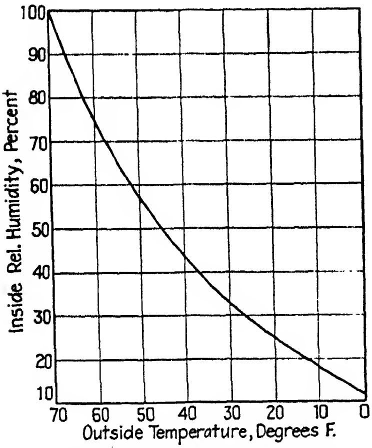


FIG. 234.—Allowable inside relative humidity for varying outside temperatures to prevent window frosting.

For example, in very cold weather, the windows may become frosted, or, in other words, the relative humidity at the inside surface of a window pane may be 98 per cent, when the average relative humidity in the room is only 30 per cent or less. In this connection, a chart prepared by the Friez Company (Fig. 234) is very useful for reference. This chart is made for an average indoor temperature of 70°F. and shows the relative humidity conditions at which condensation or frosting begins to appear on windows. This curve was calculated for an average outdoor-wind velocity of 15 miles per hour. The method of using this curve is illustrated by the following example: The indoor temperature is 70°F. and the outdoor temperature is 20°F. For these conditions (remembering that all points on the curve are calculated for an indoor temperature of 70°F.) begin by finding the 20°F. mark on the bottom horizontal scale (abscissas) and then passing up vertically from that point to intersect the curve. The

intersection point measured on the vertical scale at the left-hand side of the figure indicates that when condensation begins the inside relative humidity is only 25 per cent. Similarly, if in the same room the outside temperature is 10°F. the value of inside relative humidity when frosting begins is approximately 18 per cent.

The ordinary general humidity-control instrument (room humidistat) should be set at between 40 and 50 per cent where a windowstat is provided, thus obtaining in the room satisfactory humidity conditions during mild weather; and, in fact, at *all* times except when, because of possible frosting, the windowstat comes into operation to reduce the humidity as may be required by outside air conditions.

Dampness and dryness of the air in a room have a considerable effect on comfort. The ordinary temperature as shown by a thermometer is not a true indication of body sensitiveness to warmth or cold. The American Society of Heating and Ventilating Engineers have adopted the name "effective temperature" to define more accurately than by temperature alone the comfort conditions in a room. Effective temperature takes into account three factors: (1) Temperature; (2) humidity; and (3) air movement. As a rule, in the discussion that follows, comfort or effective temperature will be explained with the consideration only of the first two items; that is, temperature and humidity, for the reason that the practical application of the effects of air movement is difficult to introduce in designing calculations.

The relation of temperature and humidity as they are expressed in effective temperature may be well shown by the following example, where it will be assumed that the effective temperature in a room is to be 66°F. By reference to a chart—like the one given in Fig. 235 which shows the variations of effective temperature with changes in ordinary temperature and humidity—it will be observed that when the *effective temperature* is 66°F., there may be a number of conditions of temperature and humidity that will satisfy this requirement in terms of effective temperature. Thus, the effective temperature will be 66°F. when the ordinary temperature in the room is 74°F. and the relative humidity in the room is 10 per cent; also the effective temperature is 66°F. when the ordinary temperature in the room is 68°F. and the relative humidity is 70 per cent. Thus, in one case,

there is high ordinary temperature and low relative humidity; and in the other, low ordinary temperature and high relative humidity for the *same value of effective temperature.* In this connection, it is interesting to note that an *increase* of 9 per cent in relative humidity of a room will produce a corresponding change in temperature *reduction* of 1°F. With these facts in mind, it is possible to obtain constant comfort by systematically controlling the temperature in relation to *uncontrolled humidity.* The instru-

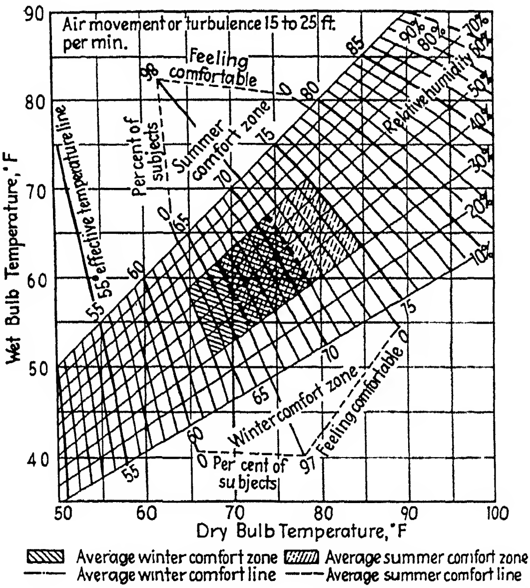


FIG. 235.—Comfort chart. (*Copyright by American Society of Heating and Ventilating Engineers, from A.S.H.V.E. Trans., Vol.* 38, 1932, *p.* 416.)

ment shown in Fig. 236 is intended to accomplish the attainment of comfortable effective temperatures by the variation of temperature to correspond with uncontrolled variations of humidity in a room. The instrument is applied in exactly the same way as the ordinary thermostat. In this instrument, there is a bimetal element *P* of the same kind as that in most of the ordinary types of thermostats. The movement of this bimetal plate makes and breaks the contact points C_1 and C_2 which regulate the operation of the heating unit. The bimetal plate is connected by a lever *L*, which is fulcrumed at *F*, to the human hairs *H* at the right-hand

side of the instrument which serve as the humidity-actuating part, for the reason that these hairs lengthen when the humidity is increased. A similar instrument called a *humidistat,* shown in Fig. 237, is for the control of humidity.

As the instrument operates in terms of degree effective temperature changes—the means of temperature measurement corresponding to true body sensitivity—the instrument omits any actual figures from the dial but shows the average condition of indoor winter comfort by the letter *W* and the summer comfort point (for air-cooling installations) by

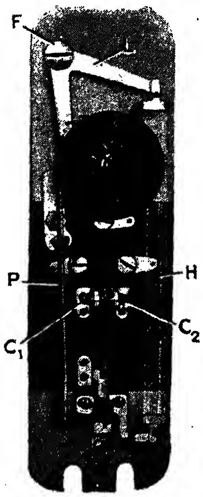


Fig. 236.—Humidistat operated by expansion and contraction of hairs.

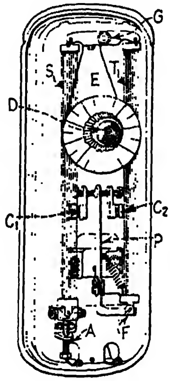


Fig. 237.—Humidistat with hair elements.

the letter *S* (not shown in the figure). These points are merely suggestive, but are based on the data collected by the A.S.H. and V.E., as shown by the effective temperature chart in Fig. 235. If in winter the control point is too low, the dial is shifted somewhat toward the letter *S*; but if too high, it is moved in the opposite direction toward the letter *W*. The winter point *W* is intended to mark as accurately as possible, the condition of effective temperature at 66°F. The instrument is constantly self-compensating to suit variations of humidity.

Comfortrol.—To attain a high degree of comfort by the adjustment of effective temperature by the variation of either temperature or humidity in a room or by the variation of both, an instrument has been devised which is called a *comfortrol* Fig. 238.

It provides these advantages by the method of resetting the *left-hand dial* in the figure, and this dial might be called a "ratio" mixer. Any adjustment made on that dial results only in a change of the components of humidity and temperature, and produces no change whatever in the normal condition of body sensitivity to warmth or cold. In this instrument, means are provided for changing the effective temperature itself to allow for the usual differences of human requirements according to temperament, occupation, or the severity of the weather. In the comfortrol, this means is provided for by the adjustment of the *right-hand dial*, which has a scale that includes a wide range of effective temperature usually from 56° to 79°F. Incidentally, these effective-temperature limits are also the practical limits of the comfort zone (Fig. 235).

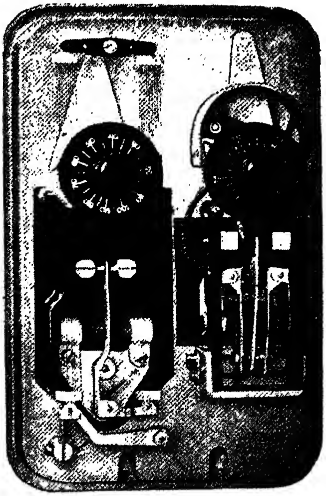


Fig. 238.—Comfortrol.

The *left-hand* dial is accurately scaled in percentages of relative humidity and is so arranged that if the relative humidity is reduced from the normal setting of about 50 per cent to a lower setting of, say, 30 per cent, in order to obviate excessive window condensation in winter, the dry-bulb-temperature-control portion of the instrument, that is, the thermostatic portion, is connected by mechanical means in such a way to the relative humidity setting or humidistat portion that the single adjustment of lowering the relative humidity setting simultaneously increases the setting of the dry-bulb-temperature dial in a ratio of approximately 9 per cent relative-humidity change (page 355) to 1°F. temperature change.

The right-hand dial is so arranged by means of a slipping-clutch mechanism that it permits raising the thermostatic point of control only, while leaving the percentage of relative humidity unchanged. This adjustment of the right-hand dial actually results in increasing the sensitivity to warmth or cold.

In a general way, the comfortrol is a combination of relative humidity and temperature control, so arranged as to be easily adjusted. It is so arranged that it becomes easy to obtain proper proportioning of the components of humidity and temperature as required for comfortable (effective) temperatures, while giving full latitude for increasing or decreasing the field of warmth or cold as may be desired.

The combination of a humidistat to be located in a room with a windowstat (page 359), the two instruments being in series connection, is shown in Fig. 239 for the operation of a solenoid valve which controls the humidification of the air delivered to the room. In the operation of the two instruments, for at least

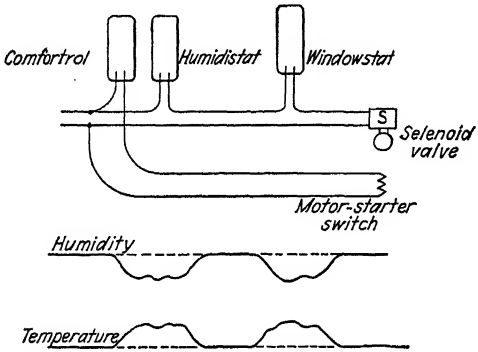


FIG. 239.—Combination of comfortrol humidistat, and windowstat.

most of the days in the year, the humidity in the room would be controlled entirely by the humidistat; but, however, with the windowstat in series, when the outside conditions produce nearly 100 per cent humidity at the glass of a window on which the windowstat is placed, the latter instrument serves as a positive shut-off which prevents the humidistat from operating again until the humidity conditions at the window are considerably different from those that produce frosting. A complete system should include also a comfortrol connected into the wiring as shown at the left-hand side of the figure; the comfortrol serving its usual purpose of adjusting automatically the effective temperature for comfort to the degree of humidity in the room. In this arrangement, the comfortrol will regulate the starting and stopping of the

electric-motor control in the heating system. The curves shown at the bottom of the figure are those of humidity and temperature, and show graphically the effect of humidity on the temperature variation, as it is when a comfortrol instrument is used for effective-temperature adjustment.

An entirely different type of humidistat is shown in Fig. 240. This instrument is operated by the expansion and contraction of a wood element *W*, which is specially treated under standard conditions for accurate humidity control. It operates by completing the electric circuit to which it is connected when the air is too dry, and breaking the circuit when the humidity of the air is too high. Its operation is not affected by temperature, and it is intended for the relative-humidity range of from 20 per cent to 50 per cent.

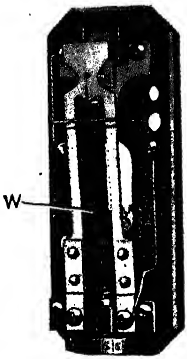


FIG. 240.—Humidistat with wood element.

Heat Required for Humidification.—Average present-day practice calls for a temperature of 70°F. and about 40 per cent relative humidity as the desirable condition to be maintained in winter. This means a vapor content of about 3.2 grains per cubic foot. Since outdoor air, even if saturated, contains only 0.5 grain at 0°F., it will be necessary to add about 2.7 grains of vapor to each cubic foot of air that leaks into the building. Converted into more usual units, this amounts to the evaporation of about 0.046 gallon of water for each 1,000 cubic feet of air. This may seem like a small quantity of water, but it requires about 400 B.t.u. for its evaporation.

Only approximate values are given in the foregoing discussion of humidity. Calculation of exact quantities requires more space than can be spared here. However, for a rough estimate it may be assumed that the heat for humidification will be 400 B.t.u. per thousand cubic feet of infiltration air. Of course, most of the time during the heating season less evaporation is needed, and therefore less heat is required. However, the greatest evaporation is called for in the coldest weather when the heating system is already taxed to its capacity.

In some sales literature for humidifying apparatus, the claim is made that, since lower temperatures are comfortable with reasonable relative humidities, heat losses are lowered, and so fuel saved. It can be shown that such savings are usually more than canceled by the heat required to evaporate the water. Furthermore, habit is so strong that most people insist on the same temperatures regardless of the humidity conditions. Therefore, the estimated capacity of the heating system, and of the oil burner, should include an allowance for the heat required by a humidifier.

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